Human enhancement and the future of BCI

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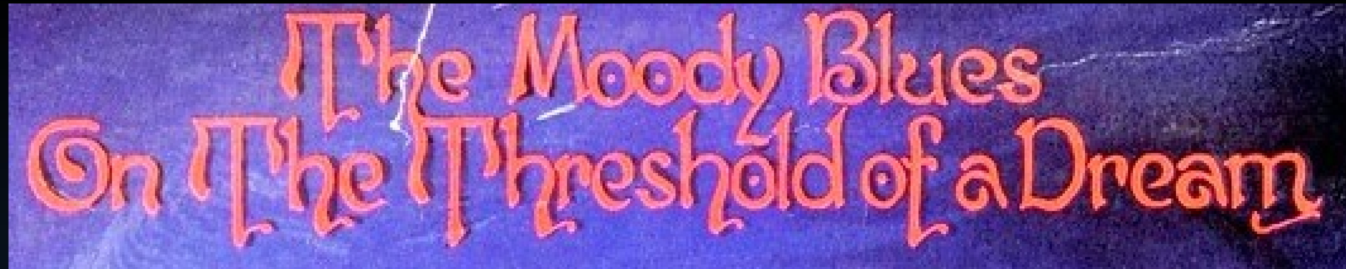
ACM ISS 11/2021



Technology for enhancement of human cognitive capabilities?

- Global brain neurotech initiatives - motivation.
- Human Enhancement and Optimization of Brain Processes - so far.
- Brain-computer-brain interfaces (BCBI)
- Understanding brain networks.
- Fingerprints of mental activity and neurotech.
- More AI + Neuroscience applications.

Duch W. (1996) *Computational physics of the mind*. Computer Physics Communication **97**: 136-153

Duch W. (2021). *Memetics and Neural Models of Conspiracy Theories*. Patterns 2(11), 2-13.
More papers on these topics.

Human Potential

Mission impossible: develop full human potential.

Neurocognitive approach:

1. understand the brain (diagnostic part),
2. control its development (infant research),
3. increase its efficiency (therapeutic, well being, neurocognitive technologies),
4. consciously control your brain states (self-control),
5. create artificial brains (AI).

Great opportunities, but also great dangers.

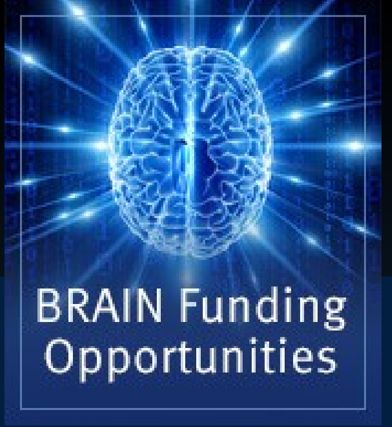
Brain processes (D. Khaneman, ***Thinking, Fast and Slow*** **2011**):

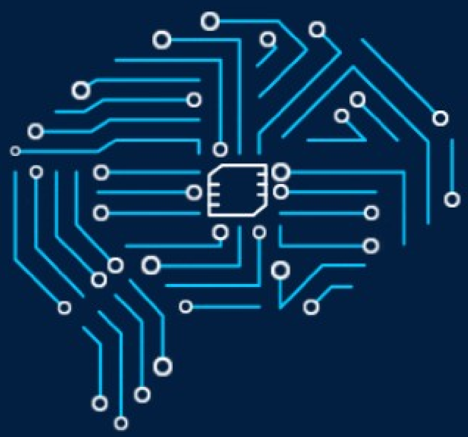
System 1: Fast, automatic, frequent, emotional, stereotypic, rigid, associative, responsible for perception, subconscious.

System 2: Slow, effortful, infrequent, logical, calculating, reasoning, conscious.

Move what you can to System 1.

BRAIN INITIATIVE





Advance Neurotechnologies

Accelerate the development and application of new neurotechnologies.

Support multi-disciplinary teams and stimulate research to rapidly enhance current neuroscience technologies and catalyze innovative scientific breakthroughs.

Human Brain Project, EU Flagship (2013), and Obama BRAIN Initiative (2013):
BRAIN=**B**rain **R**esearch through **A**dvancing **I**nnovative **N**eurotechnologies.

“Develop new technologies to explore how the brain’s cells and circuits interact … uncovering the complex links between brain function and behavior.
Explore how the brain records, processes, uses, stores, and retrieves vast quantities of information.
Help bring safe and effective products to patients and consumers.”

Since 2013 numerous exciting developments in understanding how brains work and how to use neurotechnology have been made by scientists across the globe.

The mission of IEEE Brain is to facilitate cross-disciplinary collaboration and coordination to advance research, standardization and development of technologies in neuroscience to help improve the human condition.

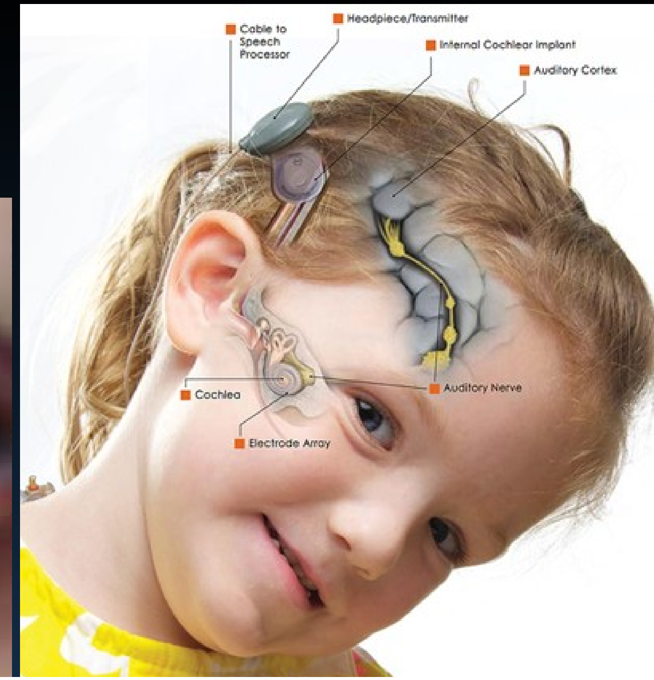
20 IEEE Societies are involved, including: **IEEE Computational Intelligence Society**; Computer Society; Consumer Electronics Society; Digital Senses Initiative; Robotics and Automation Society; Sensors Council; Signal Processing Society; Society on Social Implications of Technology; **Systems, Man, and Cybernetics Society**, Int. Neuroethics Society, and a few other societies.

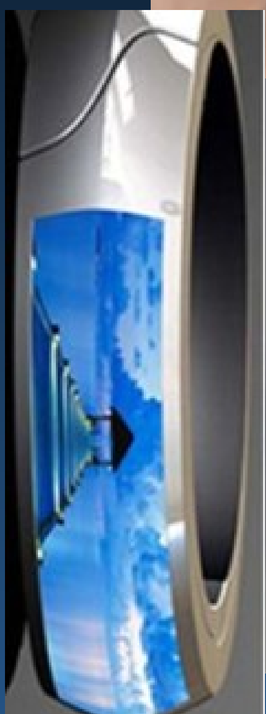
Most these societies are also involved in artificial intelligence.

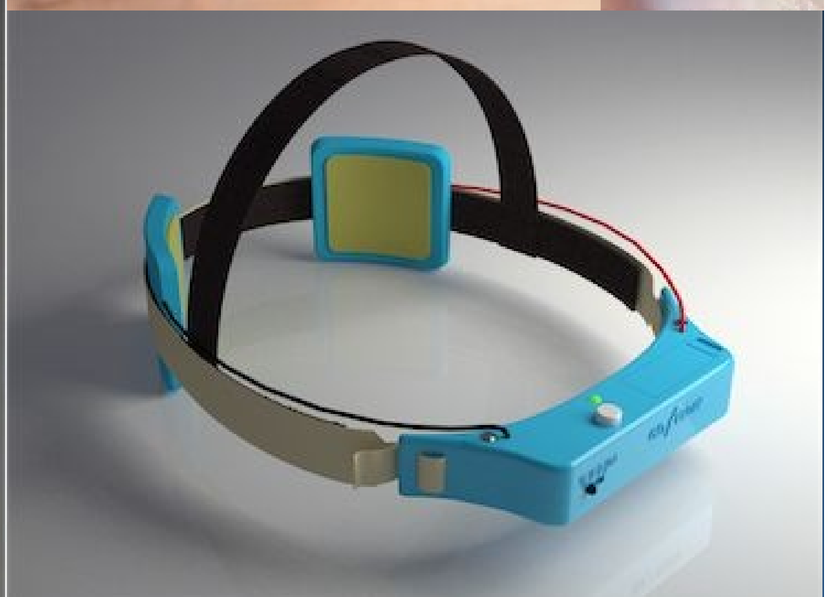
Satya Nadella (CEO, Microsoft): to celebrate National Disability Employment Awareness Month, I'm sharing examples of how technology can be applied to empower the more than one billion people with disabilities around the world.

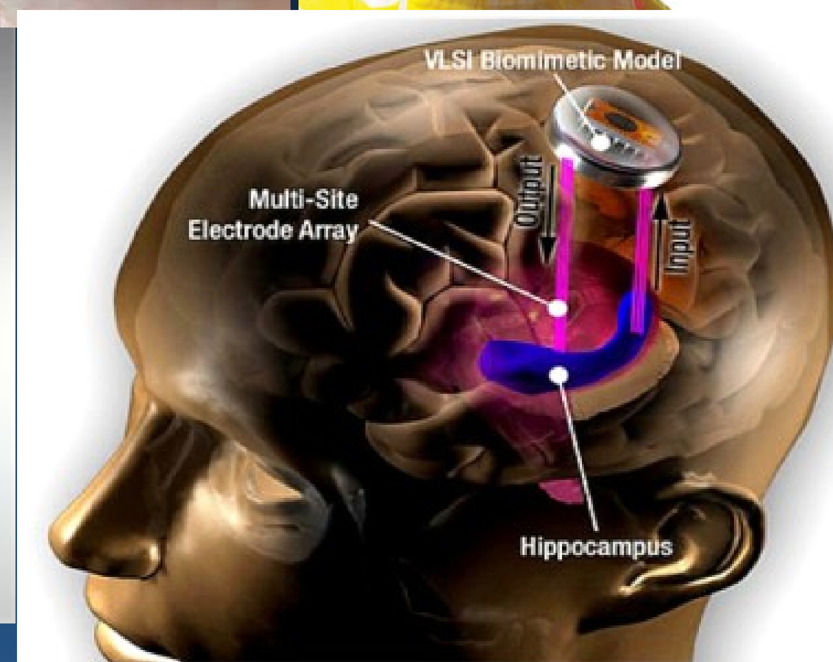
Human Enhancement
& Optimization of Brain Processes

Enhancing Perception









Improving senses: eyes, ears (cochlear implants), touch, balance, memory and attention skills… Implantation of new neurons in the brain for neurorehabilitation.

Eye-tracking: GIML/GCAF

Sharpen your brain! Improve phonematic hearing. Gaze Interaction Markup Language (GIML), and its interpreter Gaze Controlled Application Framework (**GCAF**). A platform to create applications that are controlled by direction of gaze, for infants, babies and people with various disabilities (J. Matulewski, B. Bałaj et al).

J. Matulewski, B. Bałaj, I. Mościchowska, A. Ignaczewska, R. Linowiecki, J. Dreszer, W. Duch, Learnability Evaluation of the Gaze Interaction Markup Language for a simple design of new applications. Int. J. of Human-Computer Studies (in rev. 11/2021).

GCAF/GIML

Jacek Matulewski: from infants to children and adults.
Designed to make life of medical care takers and psychologists easier.
Paralyzed people may control YouTube and other applications.

MovEye application for YouTube, many dwell-time gaze keyboard types were tested, including “molecular” and two-steps keyboards. Usability studies were performed.
J. Matulewski et al. MovEye: Gaze Control of Video Playback. ACM Symposium on Eye Tracking Research and Applications, ETRA/COGAIN 2018.
Comparison of three dwell-time-based gaze text entry methods, ETRA 2020.

Walking problems

Neuro-relax

Sounds and music may have arousing or relaxing effects.

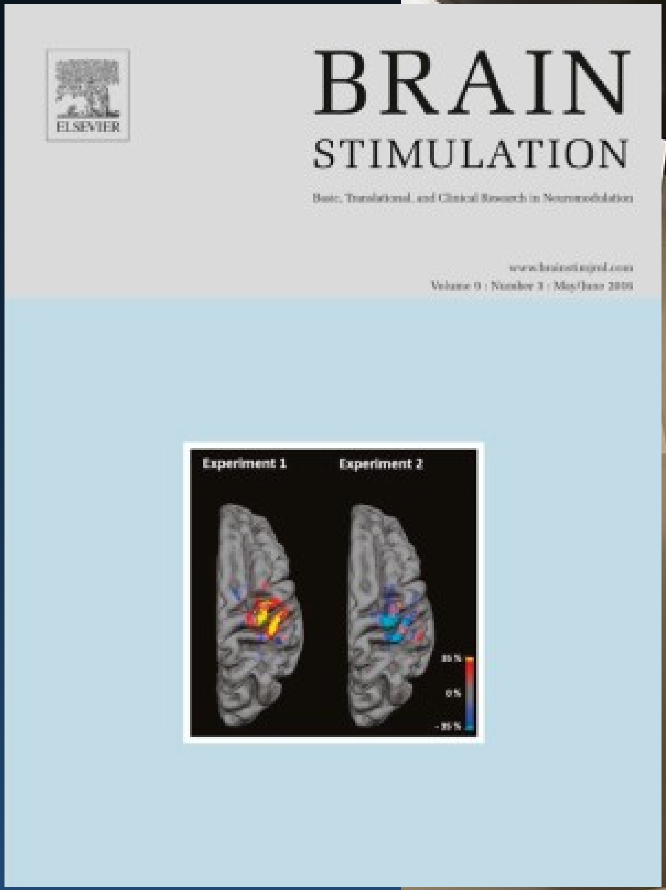
Melomind:

Simple EEG determines the relaxation level and adaptively creates sounds to increase it.

DCS for attention/relaxation

Focusing attention for a long time requires effort: PFC activates brain regions processing signals from various modalities. External stimulation using alternating currents (tDCS) or magnetic pulses (rTMS) gives good results in case of games, pilots, combat soldiers. Control yourself with a smartphone!
Thync arouses the brain before action and relaxes after.

Many kinds of brain stimulation



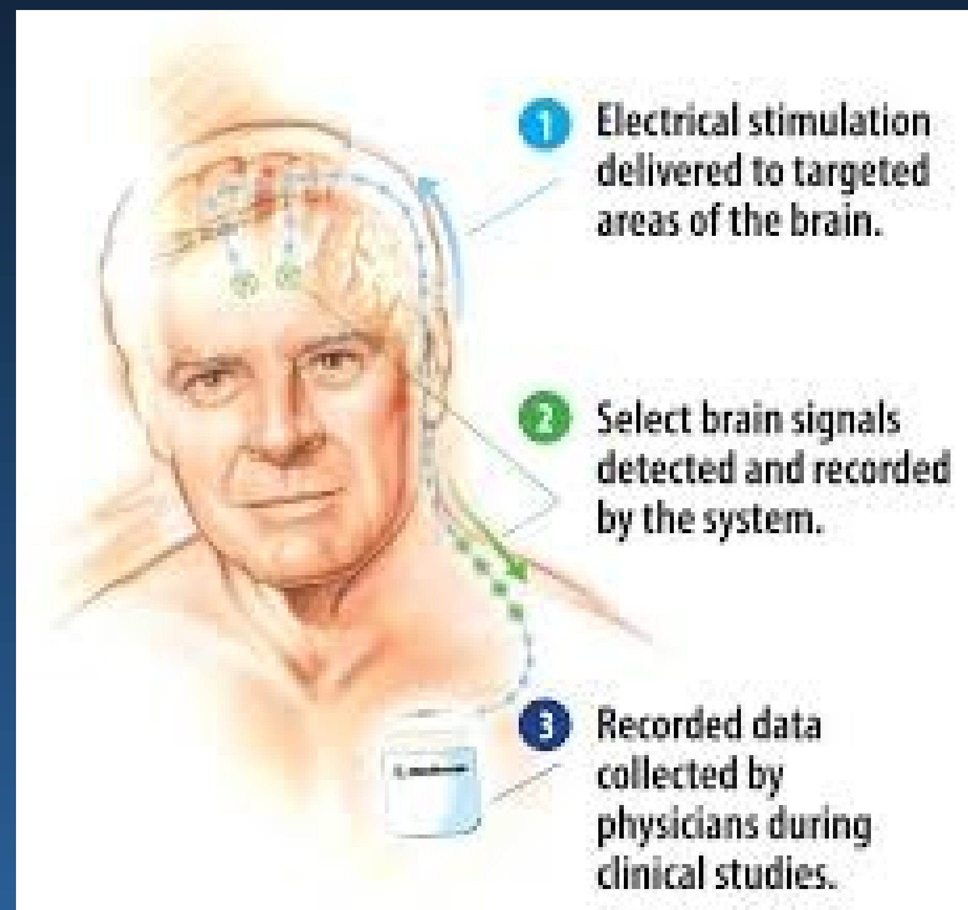
Electrical, magnetic, radiowave, ultrasounds, or focally targeted pharmacologic stimulation Popular: DCS/TMS for gaming.

Deep brain stimulation

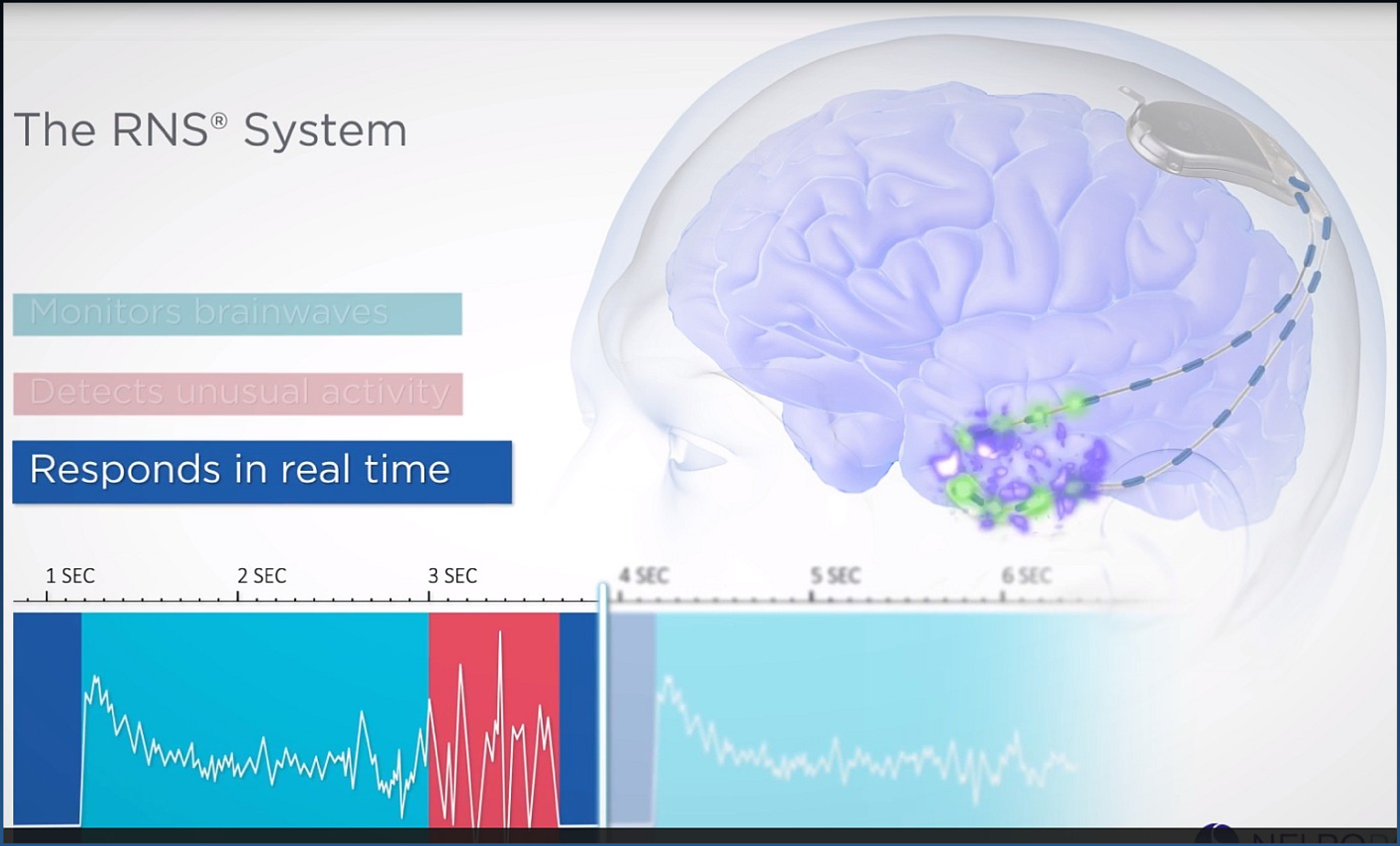
In case of Parkinson's disease, OCD, coma, persistent pain and many other conditions stimulation of peripheral nerves (in particular vagus nerve) and certain parts of the brain using external controller can help.

Non-invasive approach using ultrasound interference is possible.

What brain functions can be consciously controlled?



Epilepsy

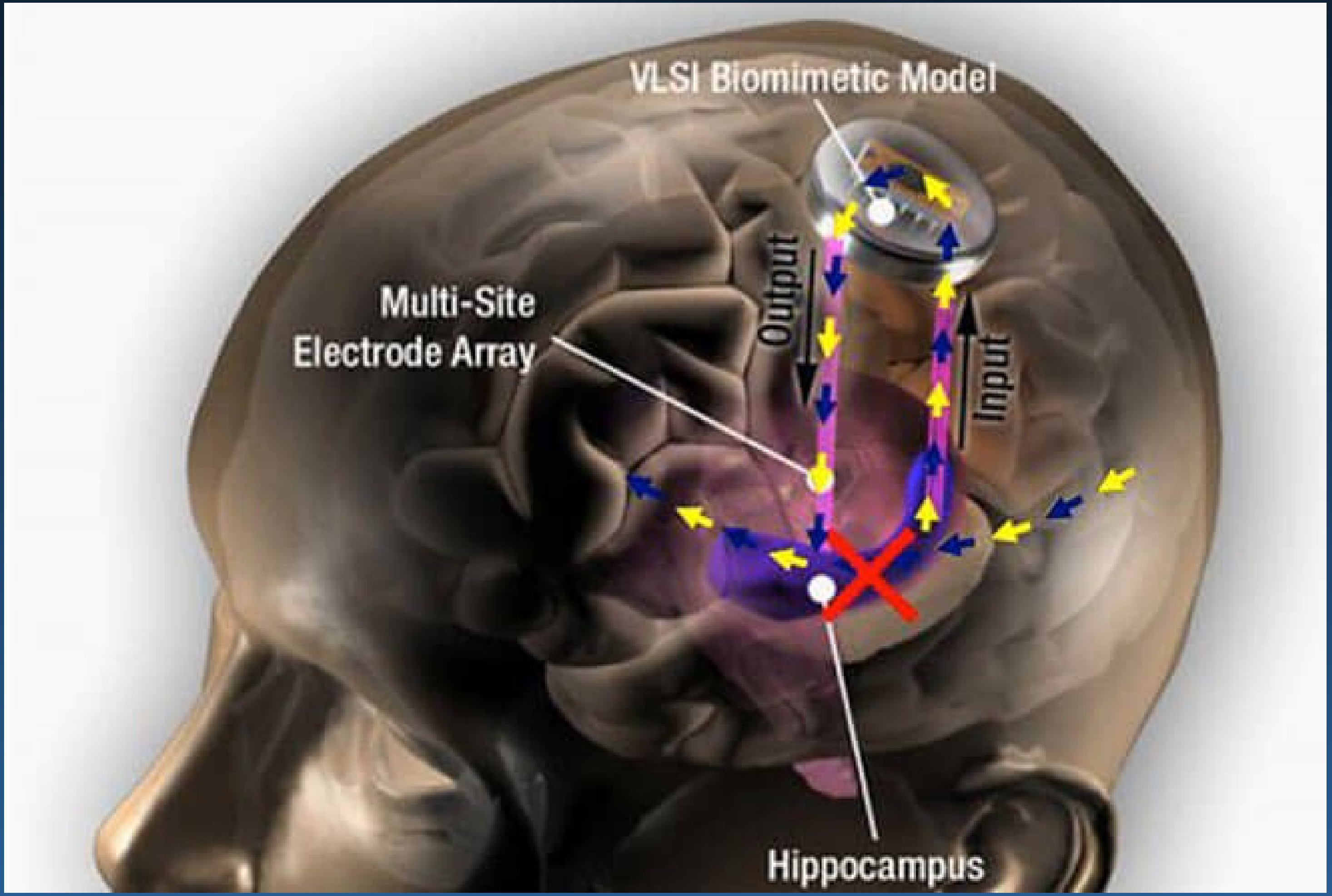


1% of population suffers from epilepsy, if pharmacology does not help neurostimulation based on close loop may help – RNS system is now commercial.

Memory implants

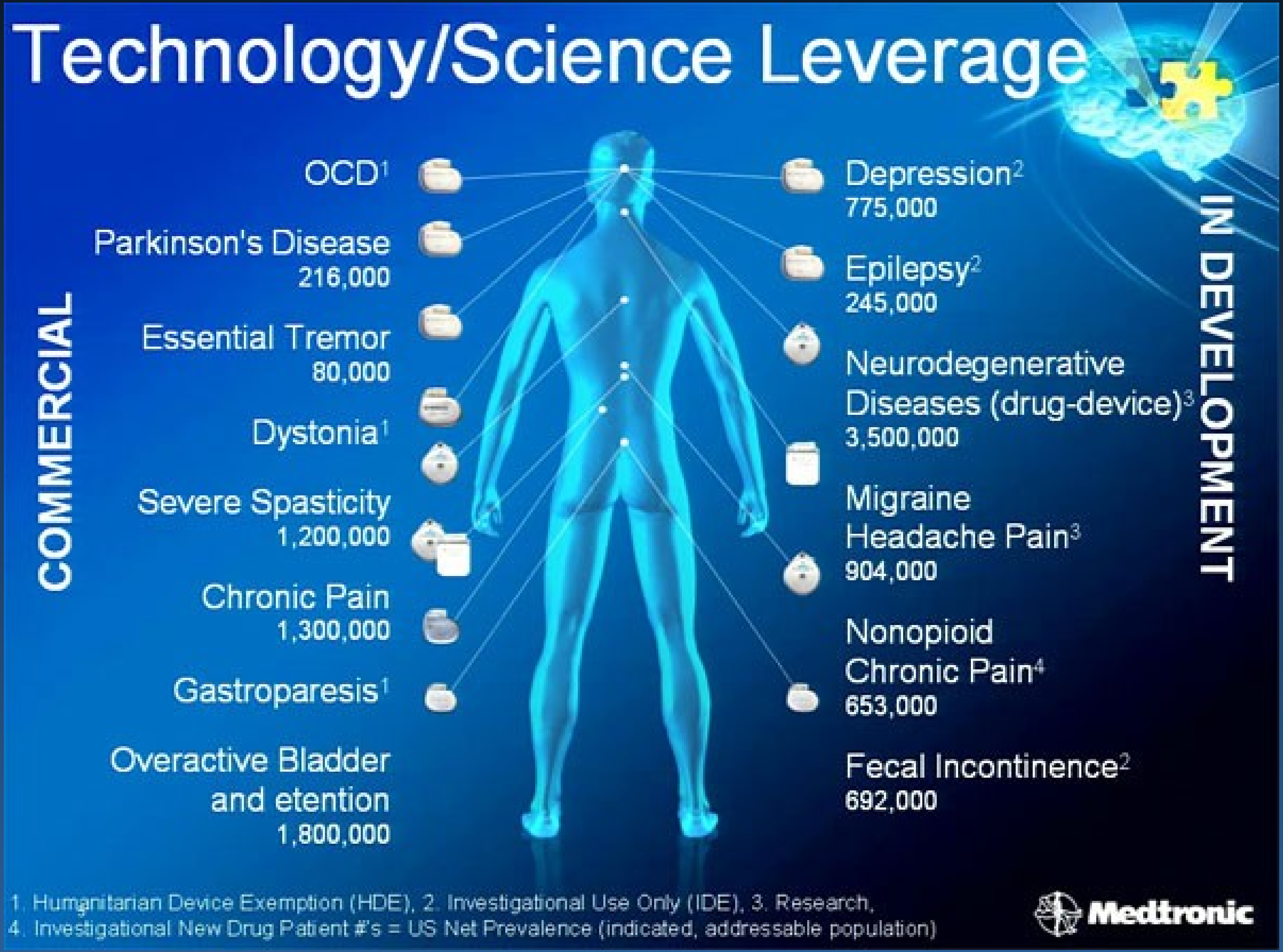
Ted Berger (USC, Kernel): hippocampal neural prosthetics facilitate human memory encoding and recall using the patient's own hippocampal spatiotemporal neural codes. Tests on rats, monkeys and on people gave memory improvements on about 35% (J. Neural Engineering 15, 2018).

DARPA: Restoring Active Memory (RAM), new closed-loop, non-invasive systems that leverage the role of neural "replay" in the formation and recall of memory to help individuals better remember specific episodic events and learned skills.



Neuromodulation

Cochlear implants are common, but deeper implants that stimulate or even replace some brain structures start to appear, not only for deficits at the level of perception, but to regulate cortical neural processes. Market 10B$ (2021), 25B$ in 2027.



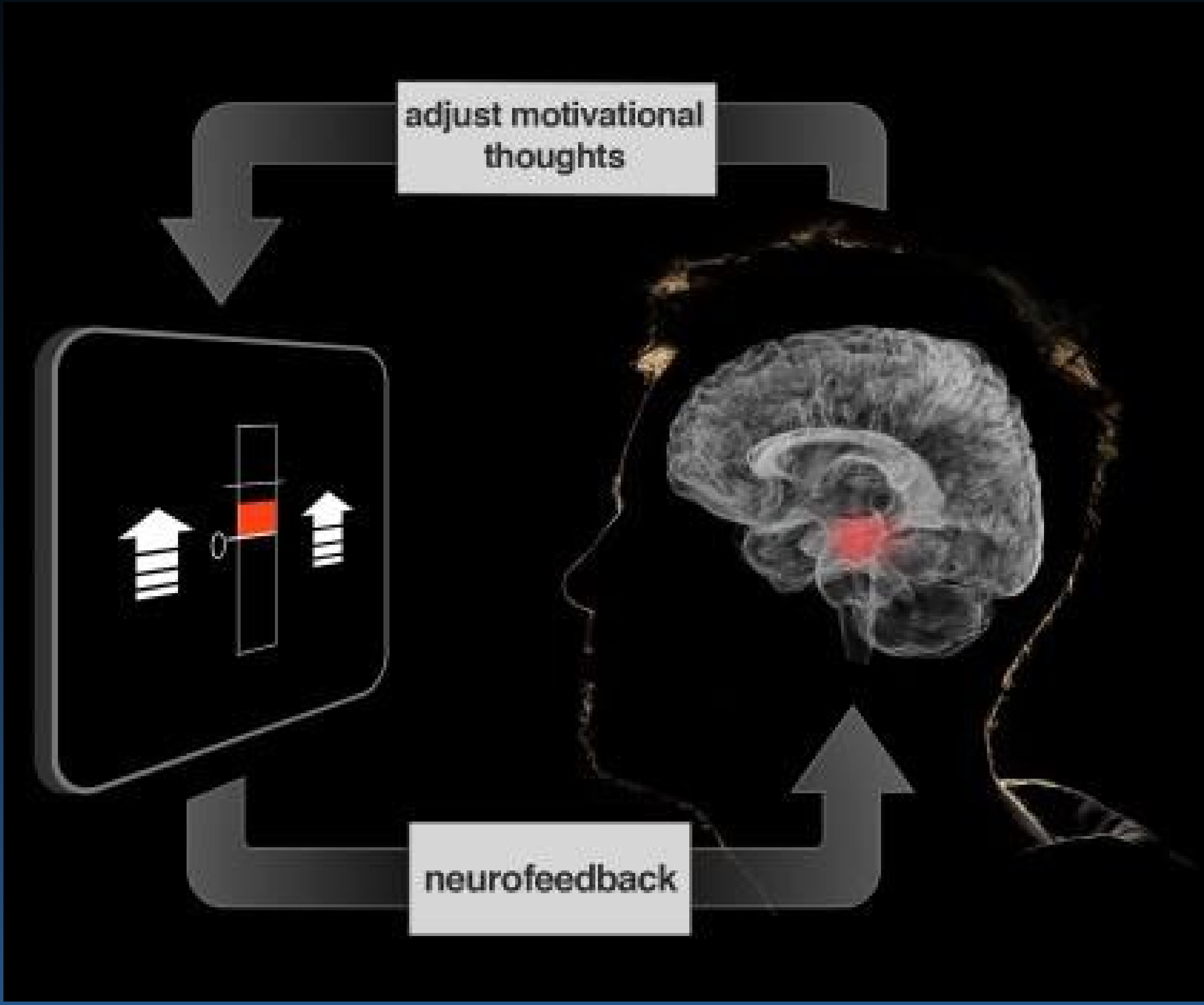
Neurofeedback: hearing/seeing brain states

Brain may stimulate itself

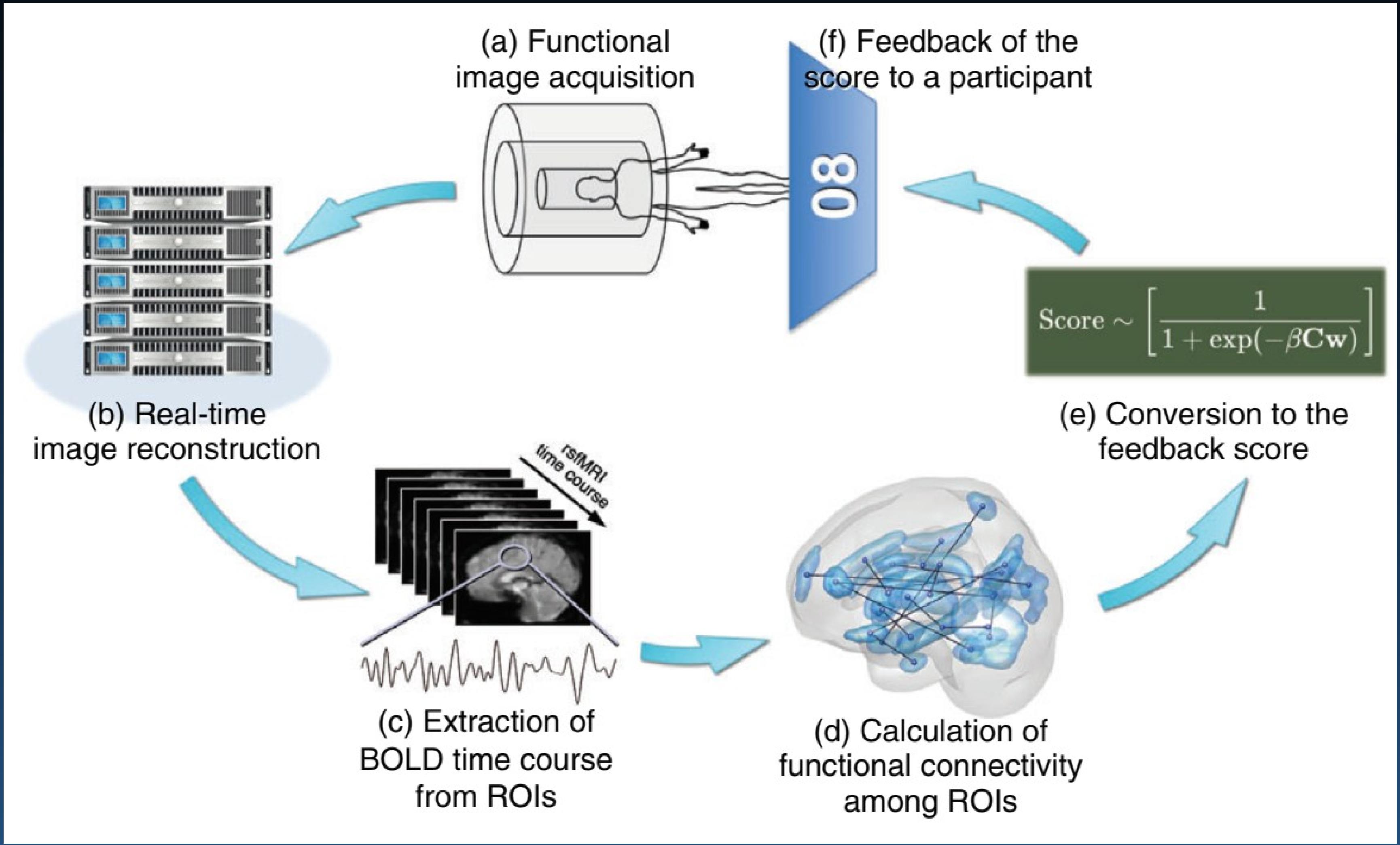
Used in clinical practice, aimed mostly at the increase of alpha rhythms for relaxation, sometimes combined with theta rhythms.

Critical review of existing literature shows that it is **not very effective.**

New forms based on brain fingerprinting needed.



Neurofeedback may repair network?

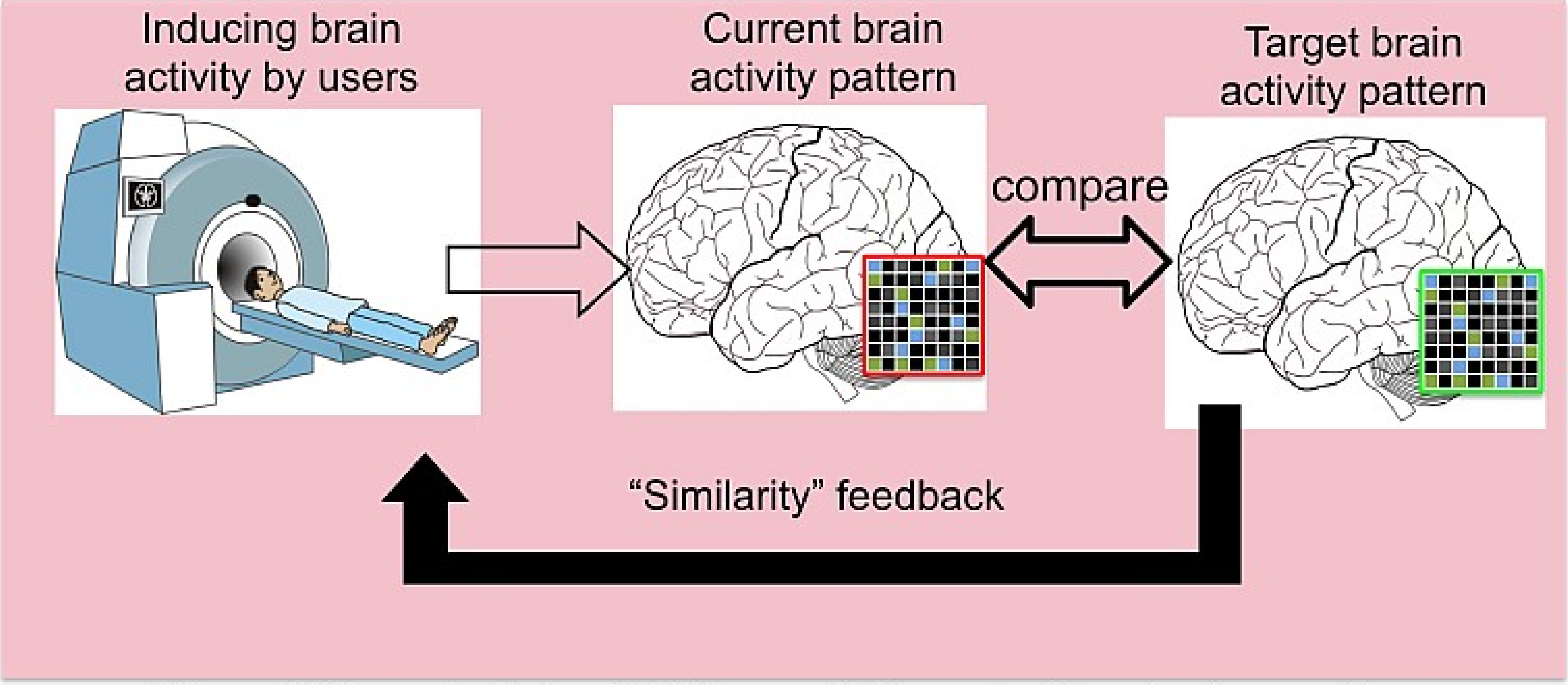


Megumi F, Yamashita A, Kawato M, Imamizu H. Functional MRI neurofeedback training on connectivity between two regions induces long-lasting changes in intrinsic functional network. *Front. Hum. Neurosci.* 2015; **9**: 160.

Real-time fMRI neurofeedback

DecNef: OCD, Pain

; needs a decoder for each patient and its application is currently limited to OCD and pain. In cases of high decoding performance, the success rate is 10/10. The long-term effect depends on the situation; from three to five months in 2/3 studies.



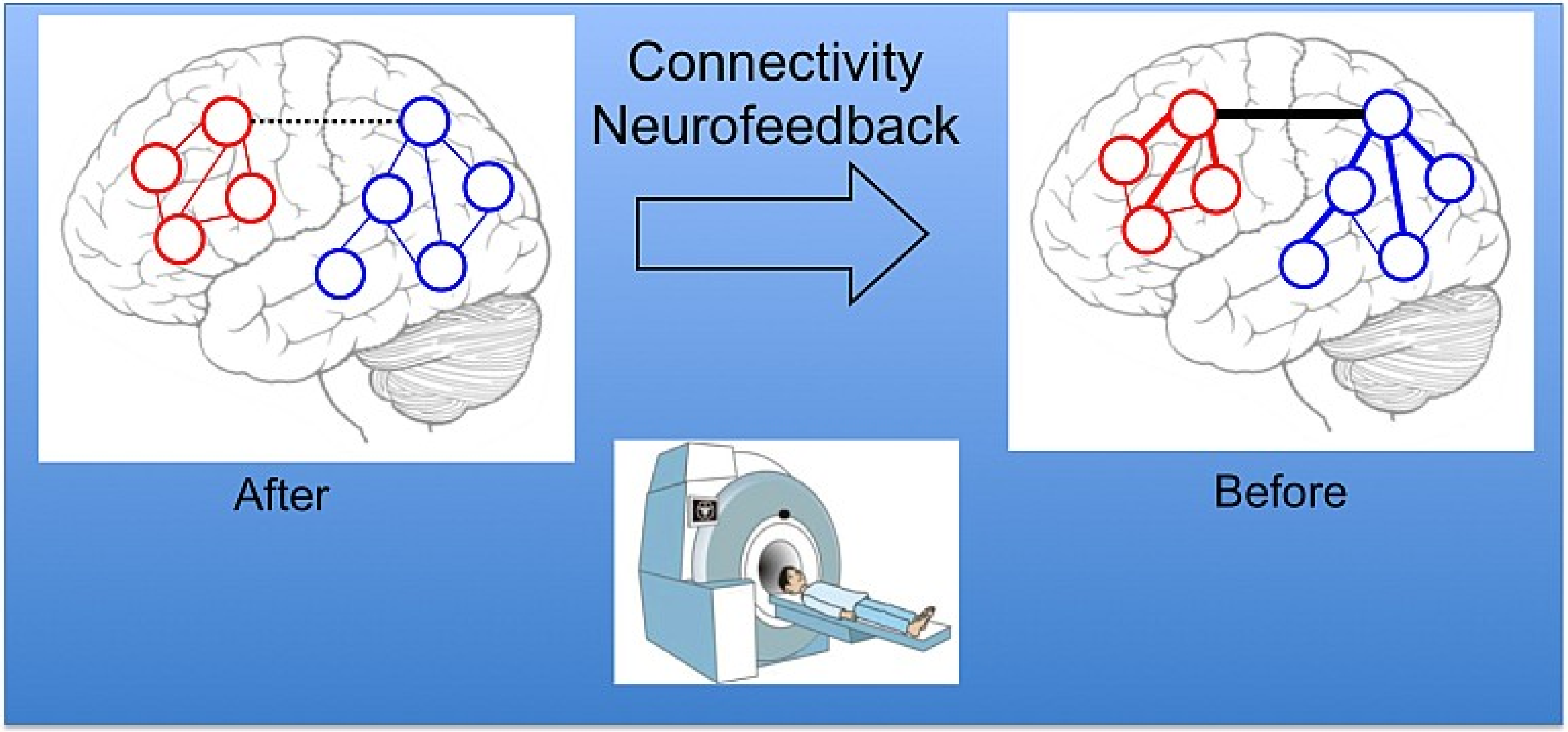
Shibata K, Watanabe T, Sasaki Y, Kawato M: Perceptual learning incepted by decoded fMRI neurofeedback without stimulus presentation. *Science*, **334(6061)**, 1413-1415 (2011)

Real-time fMRI neurofeedback

Connectivity Neurofeedback: FCNef

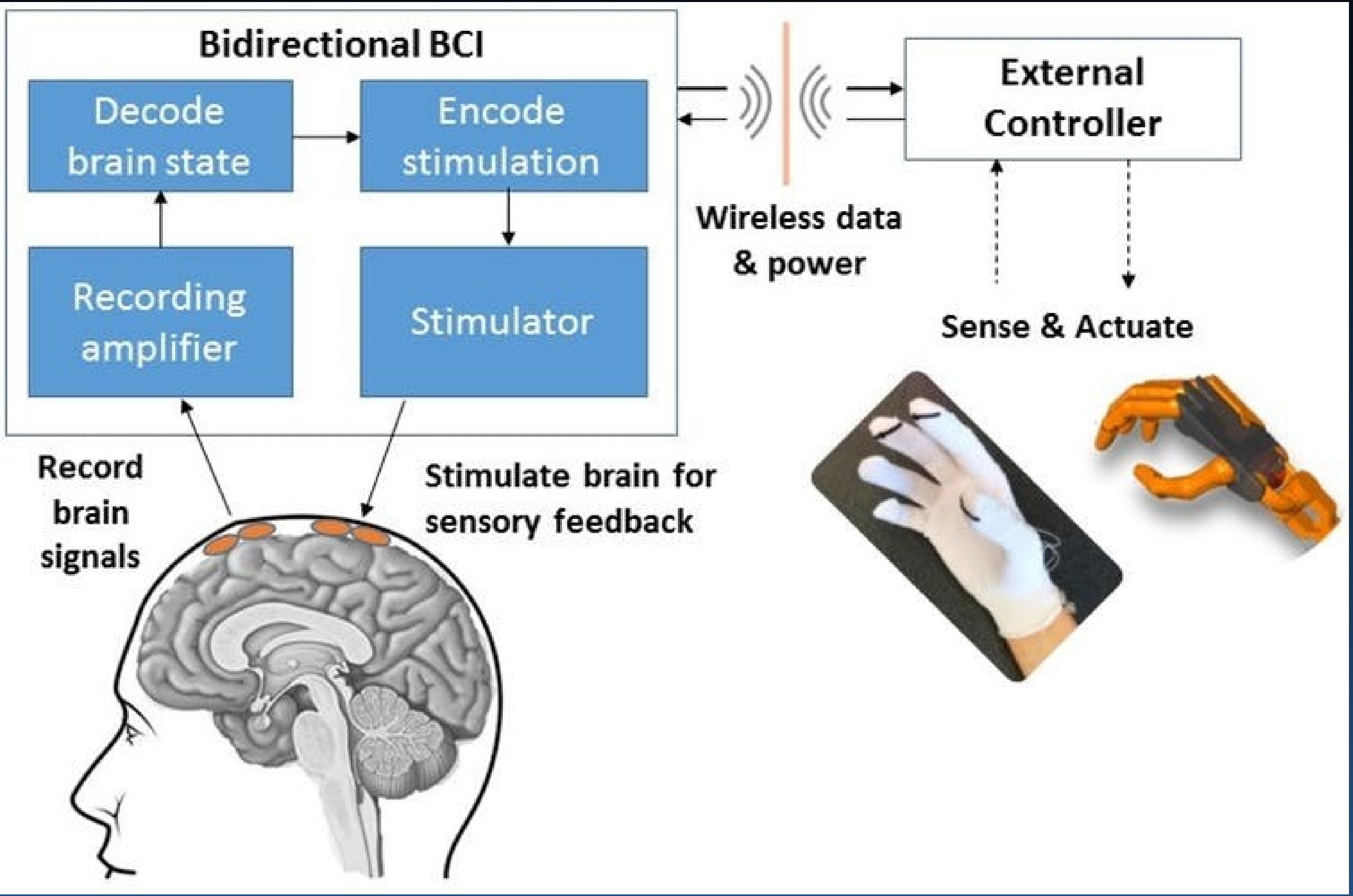
ASD, Depression, Schizophrenia

Ready-made treatment based on an across-patient functional-connectivity biomarker. NF training for four days has long-term effect at least two months.



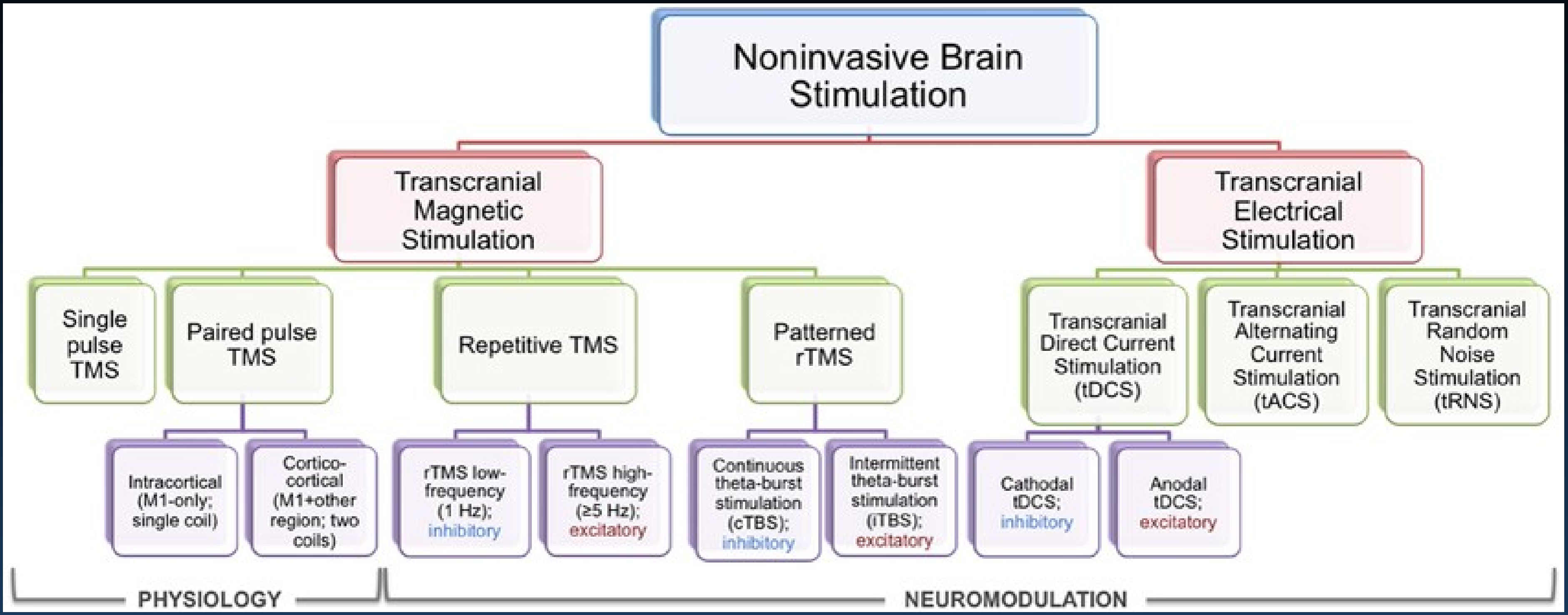
Megumi F, Yamashita A, Kawato M, Imamizu H: Functional MRI neurofeedback training on connectivity between two regions induces long-lasting changes in intrinsic functional network. *Frontiers in Human Neuroscience*, **9(160)**, doi: 10.3389/fnhum.2015.00160 (2015)

Brain-Computer-Brain Interfaces (BCBI)



Closed loop system with direct brain stimulation for self-regulation is faster than neurofeedback. Body reactions may be evaluated using sensory signals in Virtual Reality.

Brain stimulation



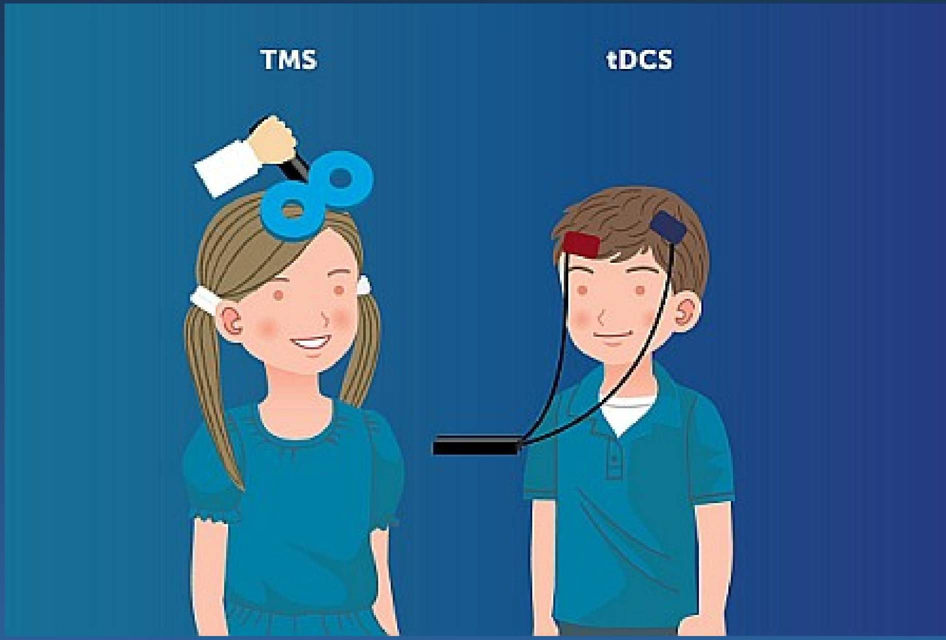
ECT – Electroconvulsive Therapy

VNS – Vagus Nerve Stimulation

Stimulation using ultrasound, laser …

Too complex? Smartphones are also complex.

Attention? Just stimulate your cortex,
no conscious effort is needed!

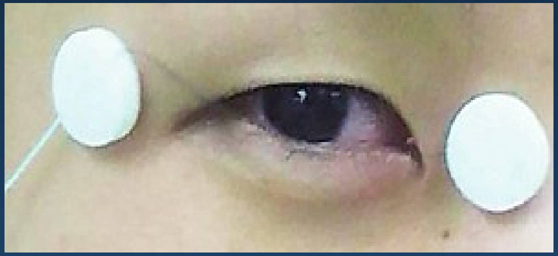


Why neuromodulation/feedback works?

- **Neurorehabilitation**: some successes but mechanism is unknown.
- Hypothesis 1: changing the activation thresholds of neurons (sensitization and inhibition) changes the way brain networks work.
- Hypothesis 2: neuromodulation leads to changes in cardiovascular coupling to neurons, improving blood flow in microvessels.

This can be tested with non-invasive transorbital Alternating Current micro-Stimulation device (hACS), used in Magdeburg and Berlin clinics.

Sabel (2018) **Restoring Low Vision.** Amazon, 251 pp.

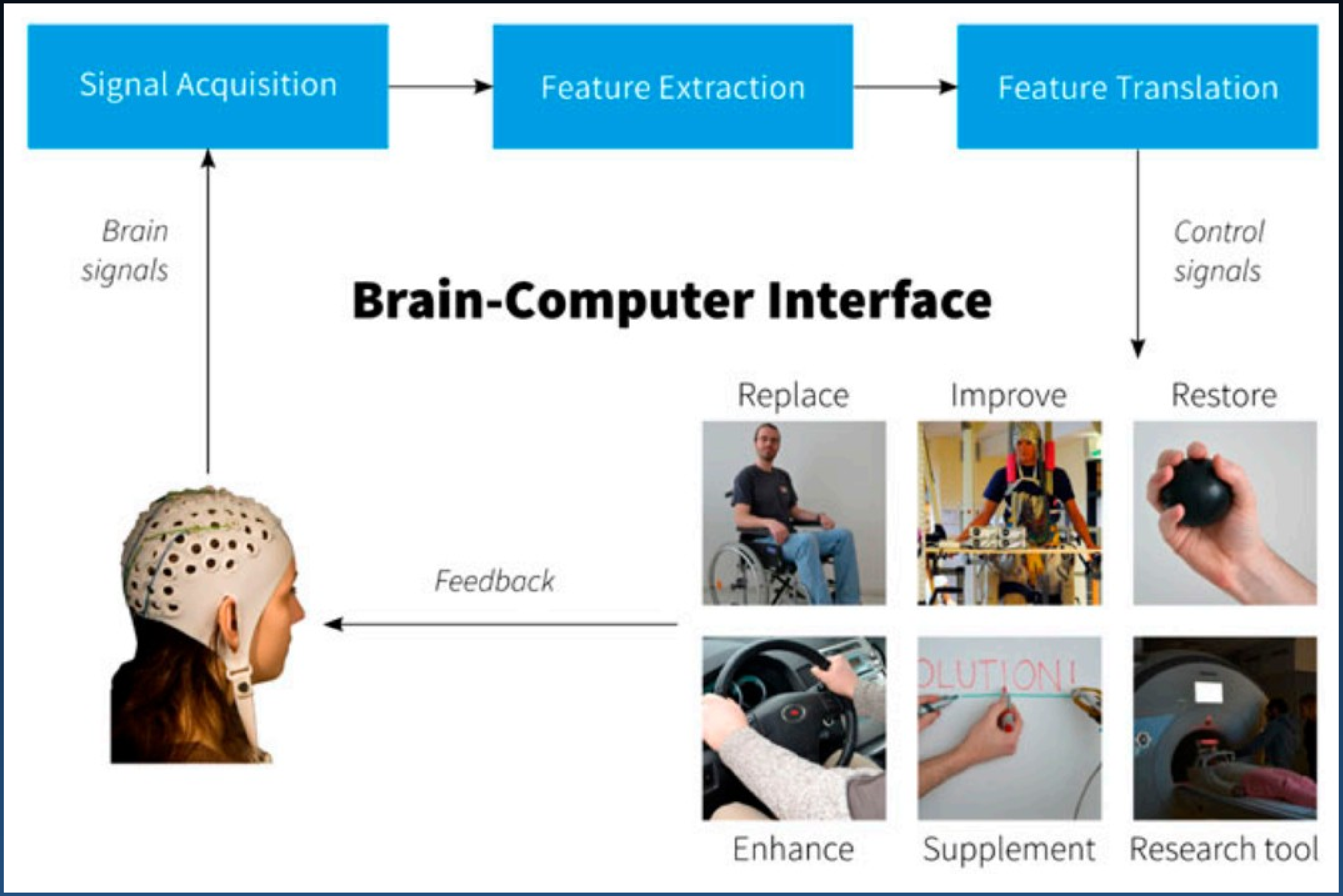


We would like to understand how to optimize parameters of neuromodulation to increase flow of visual information in the brain.

Why neurofeedback works? Mechanism is not known. Models are quite complex, involving several brain structures: frontal cortex (goals), striatum (rewards, motivation, reinforcement), thalamus (sensory relay) and cortex (cognitive/affective processing).

Brain-computer-brain interfaces

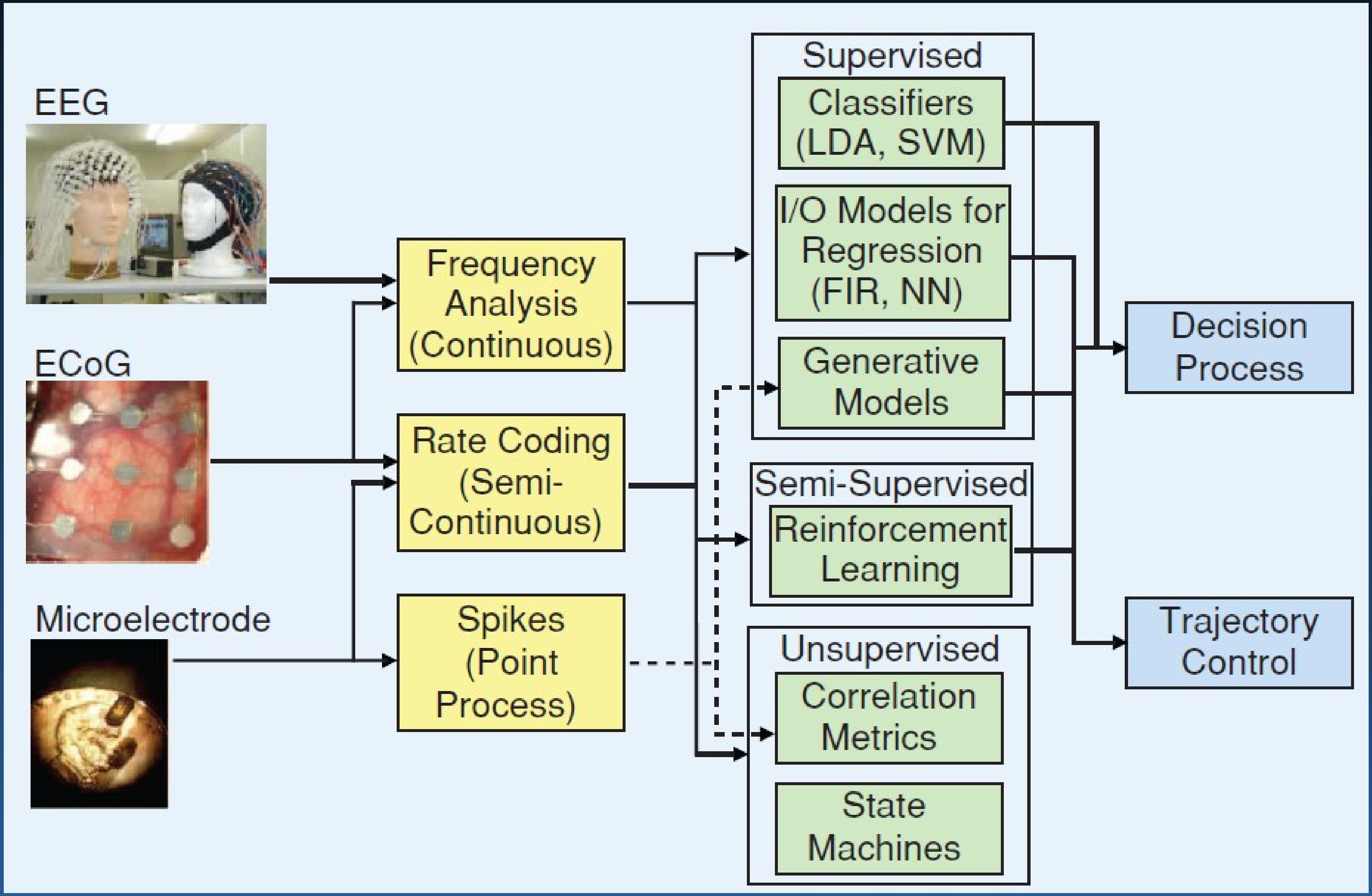
BCI Applications



Signals: invasive (brain implants), partially invasive (ECoG), and non-invasive.

BCI: wire your brain …

Non-invasive, partially invasive and invasive signals carry progressively more information, but are also harder to implement. EEG is still the king!



Learning skills

Engagement Skills Trainer (EST) procedures are used by USA army.

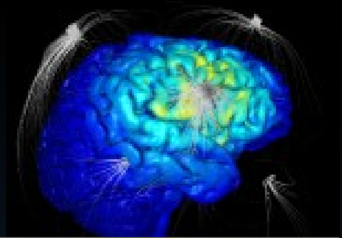
Intific Neuro-EST uses EEG analysis and mulit-channel transcranial simulation (HD-DCS) to pre-activate the brain of the novice in areas where the expert brain is active.

Real-life transfer learning …

HD-tDCS may have 100 channels, neurolace and nanowires much more.

Experiments with direct injection of microcurrents into the motor cortex were done with monkeys – it works!

HD DCS for resonance of brains

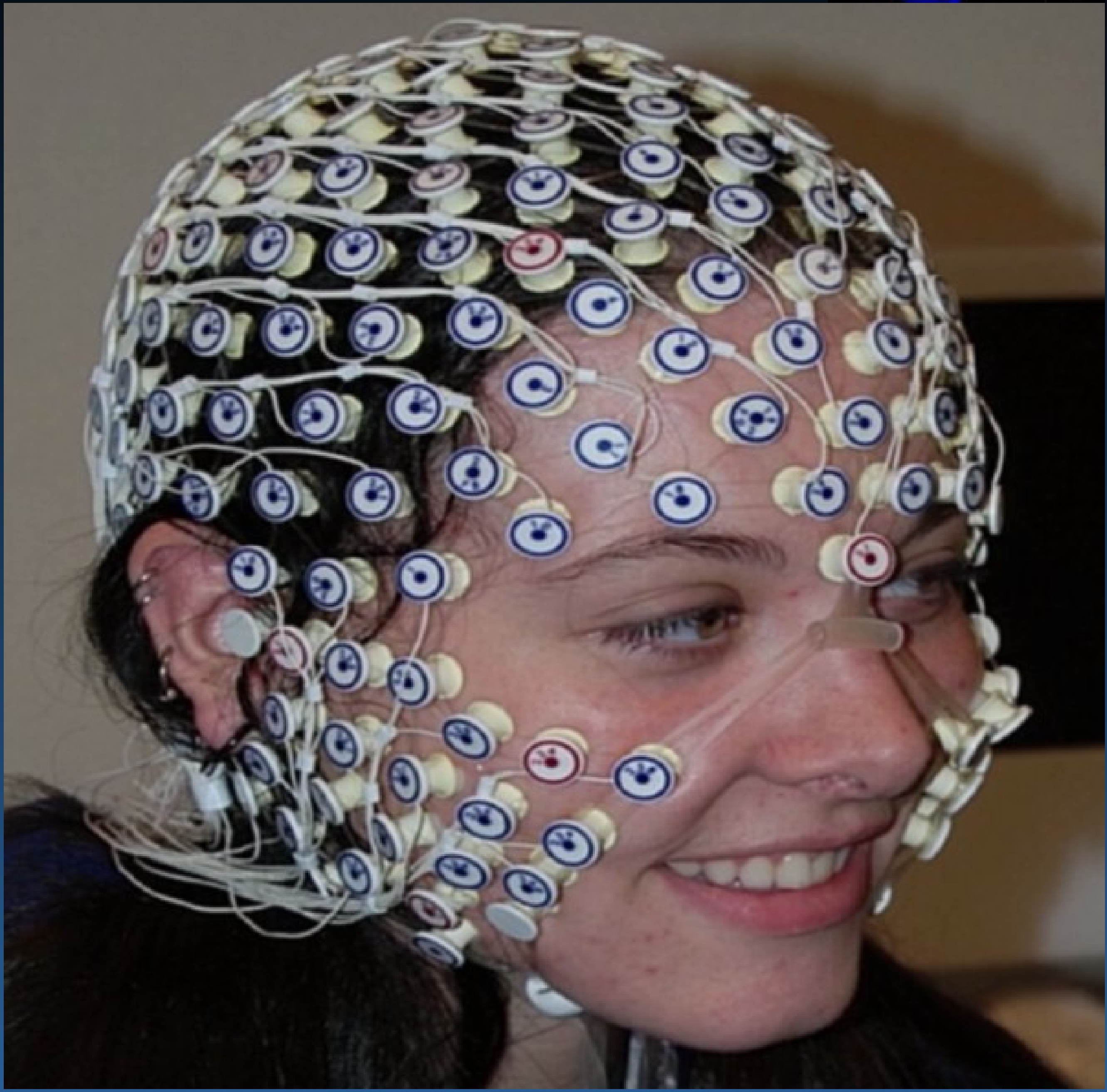


Reading brain states
 => transforming to common space
=> duplicating in other brains …

Depression, neuro-plasticity, pain, psychosomatic disorders, teaching!

Multielectrode DCS stimulation with 256 electrodes induces changes in the brain increasing neuroplasticity.

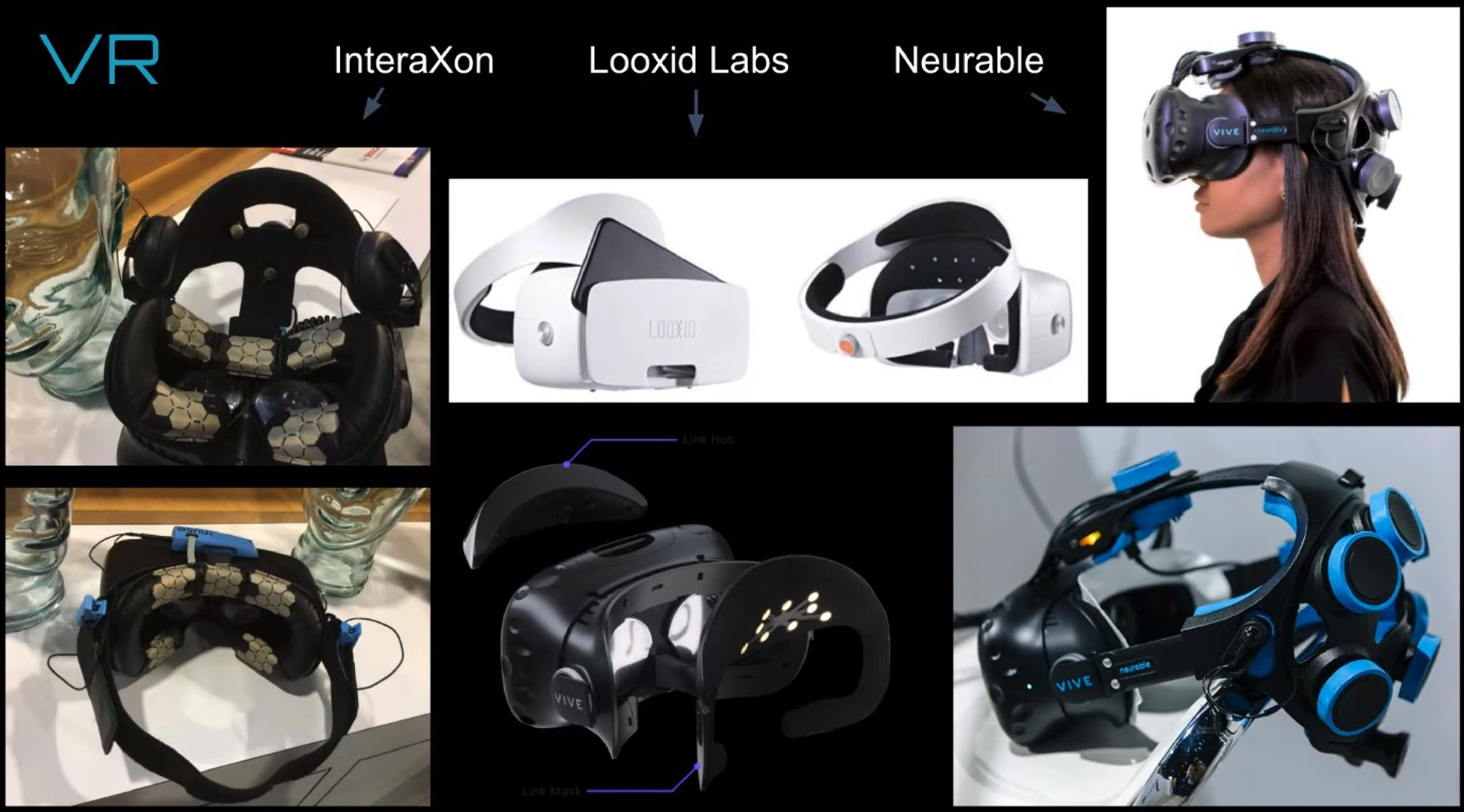
But **no-one really knows** why it works …



BCI Tools I

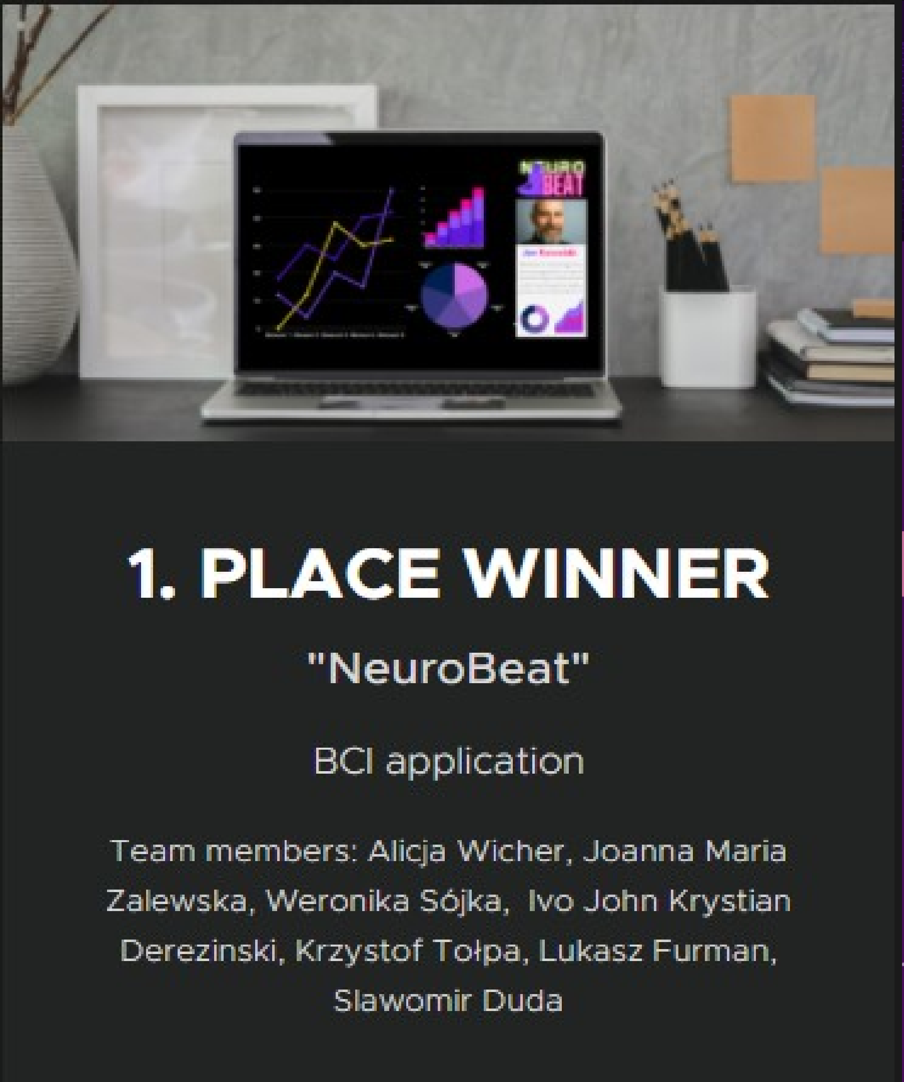
Many inexpensive EEG solutions, but analysis of brain signals is always hard.

VR + EEG



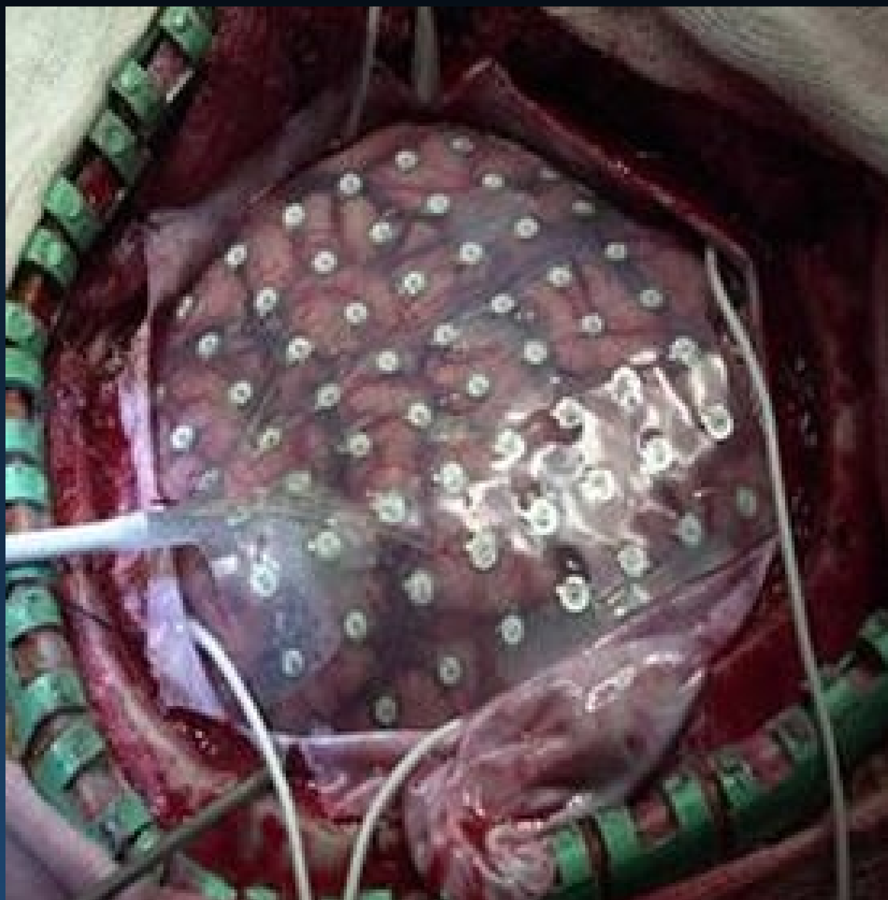
Combination of Virtual Reality with BCI has great potential.


VIRTUAL BR41N.IO HACKATHON
April 17-18, 2021
during the
Spring School 2021*
IEEE brain
g.tec
*BR41N.IO and Spring School 2021 are part of g.tec's Teaching Plan 2021 with more than 140 hours of online courses and lectures.


1. PLACE WINNER
"NeuroBeat"
BCI application
Team members: Alicja Wicher, Joanna Maria Zalewska, Weronika Sójka, Ivo John Krystian Derezinski, Krzystof Tołpa, Lukasz Furman, Slawomir Duda


IMPROVING HUMAN DAILY LIFE FUNCTIONING
NEUROHACKATOR 2021
21. - 23. MAY 2021 // ONLINE
FRIDAY
Organisers presentation
workshops with Judges
SATURDAY
Project development in groups
STARTS 10 a.m.
SUNDAY
Evaluation
ENDS 10 a.m.
working 24h
REQUIREMENTS:
1. Create a team consisting of 3-5 people.
2. Fill in the Registration Form (available on Facebook event).
DO YOU HAVE ANY QUESTIONS?
Write an e-mail:
NEUROTECHTOR@GMAIL.COM
Neurotechnology Scientific Club
Center for Modern Interdisciplinary Technologies
at Nicolaus Copernicus University in Toruń
Wileńska 4 Street

Partially invasive interfaces



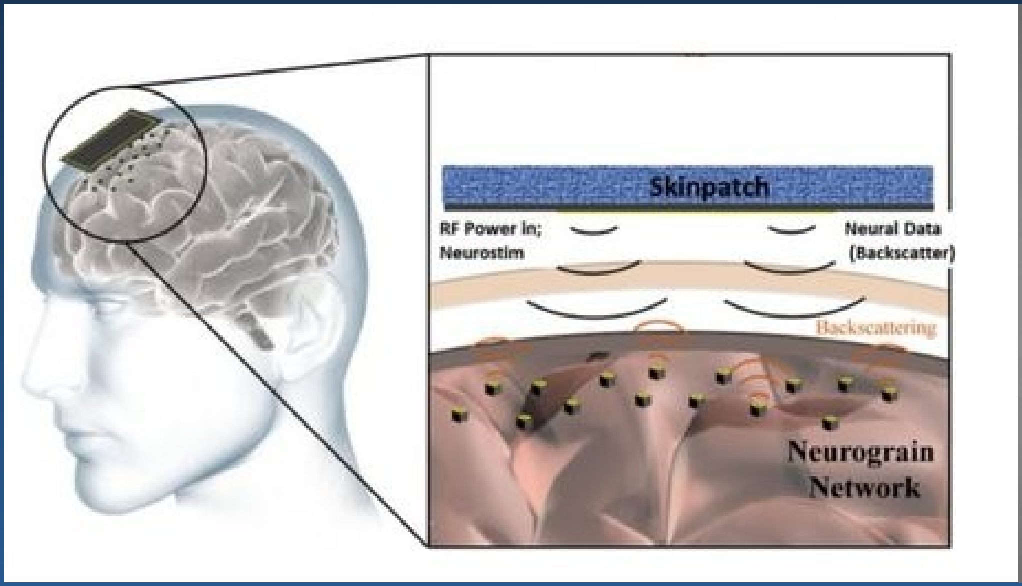
Electrocorticography gives much better signal than EEG.
Epilepsy, Obsessive-Compulsive Disorder, Phobias … if you know how to run electric currents through your brain you can control your mental states in a conscious way.
New stable electrodes stay for years on your cortex.

Million nanowires in your brain?

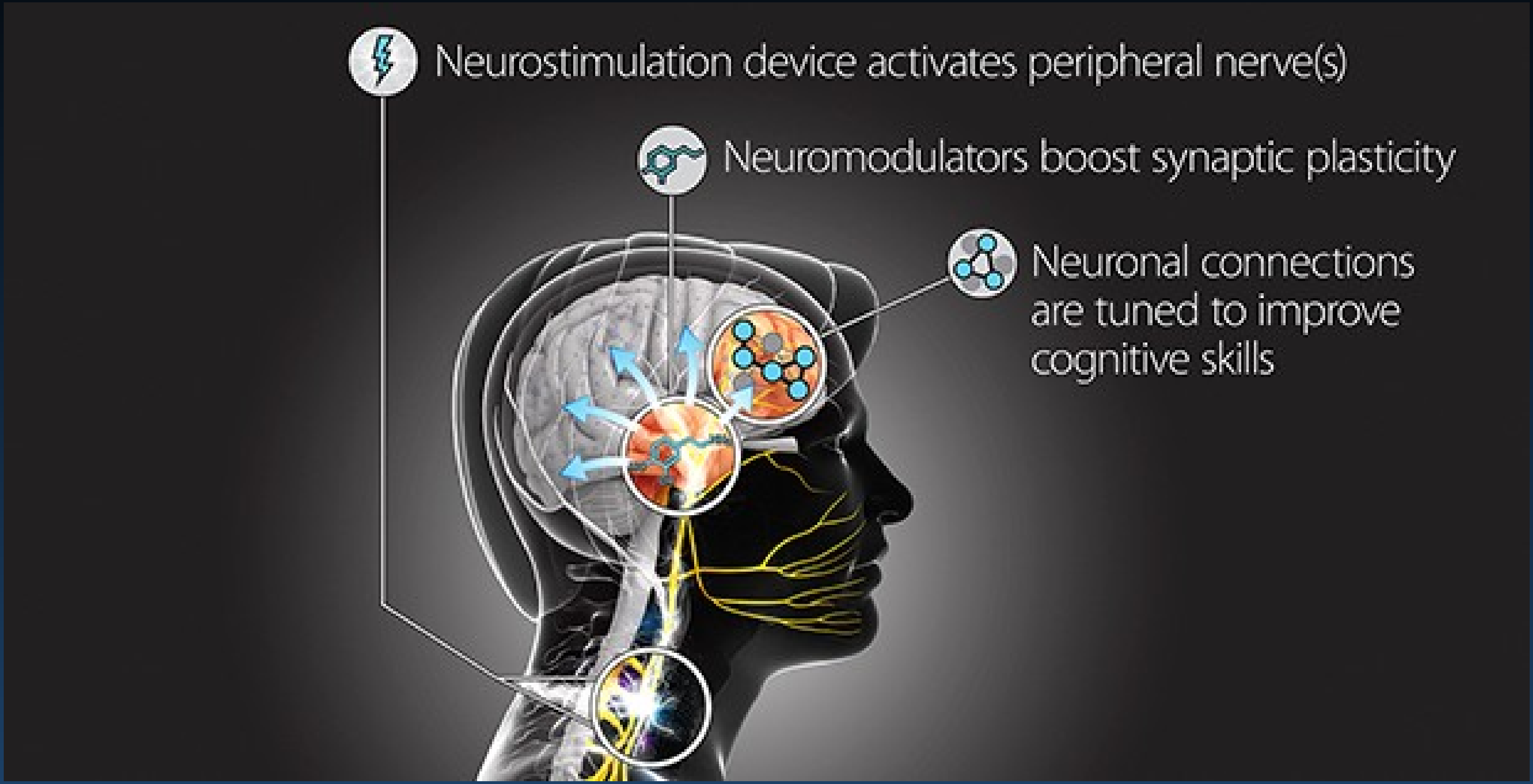
DARPA (2016): **Neural Engineering System Design (NESD)**
Interface that reads impulses of 10^6 neurons, injecting currents to 10^5 neurons, and reading/activating 10^3 neurons.

DARPA Electrical Prescriptions (ElectRx) project enables "artificial modulation of peripheral nerves to restore healthy patterns of signaling in these neural circuits. ElectRx devices and therapeutic systems under development are entering into clinical studies."

Elon Musk Neuralink project for cortex stimulation – control your brain!
Neural dust, neurograins – microscopic wireless sensors implanted in the brain.



Targeted Neuroplasticity Training



DARPA (2017) Programs: **TNT to** enhance learning of cognitive skills, tuning neurons reduce cost and duration of the Defense Department's extensive training regimen, while improving outcomes, accelerate learning time needed to train foreign language specialists, intelligence analysts, cryptographers etc.

Restoring Active Memory (RAM) program is aimed at neurotechnologies to facilitate memory formation/recall in the injured brain.

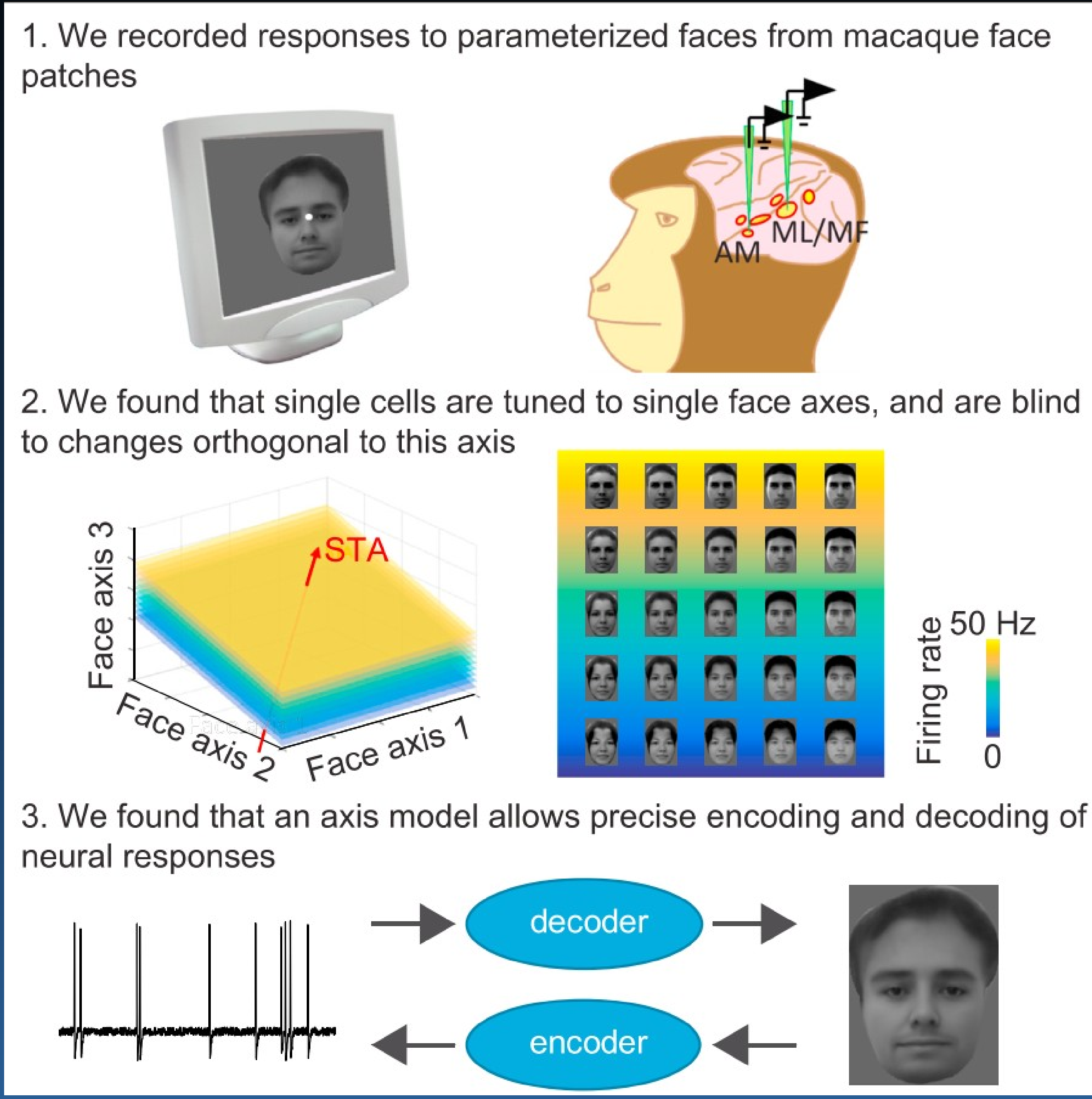
Neural screen

How are images coded in brains and recreated in conscious experiences?

Visual cortex extracts specific features and their combinations are remembered as face.

Detailed recognition was possible recording from just 205 neurons. Some neurons react only at specific deformation of images.

L. Chang & D. Y. Tsao, The code for facial identity in the primate brain. *Cell* (2017)



Mobile deep brain recording and stimulation platform in 4-kg backpack.

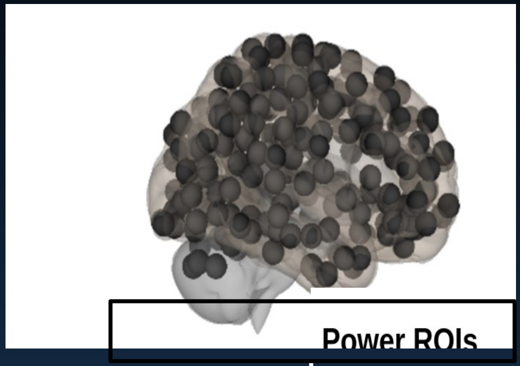
Real-time data collection from deep brain implant, using EEG cap and various heart and breathing sensors plus intracranial EEG and stimulation.

U. Topalovic, et al. 2020. Wireless Programmable Recording and Stimulation of Deep Brain Activity in Freely Moving Humans. Neuron 17/09/2020.

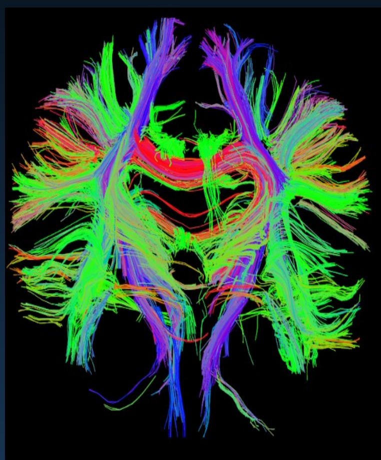
Understanding brain networks.
Space for mental states

Human connectome and MRI/fMRI

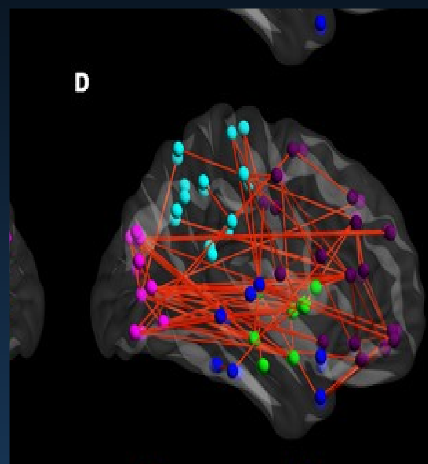
Node definition (parcelation)



Structural connectivity

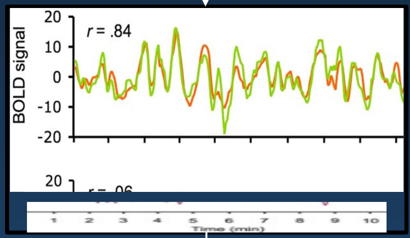


Functional connectivity

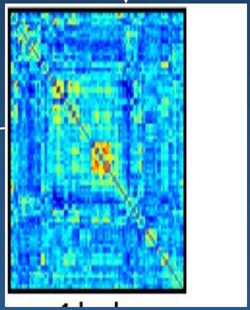


Signal extraction

Correlation calculation

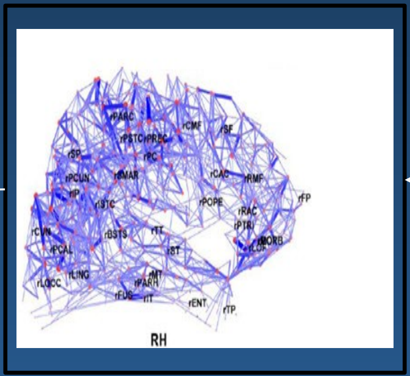


Correlation matrix

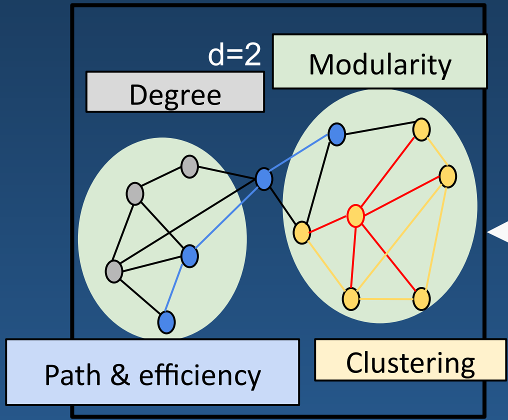


Binary matrix

Whole-brain graph



Graph theory



Many toolboxes are available for such analysis.

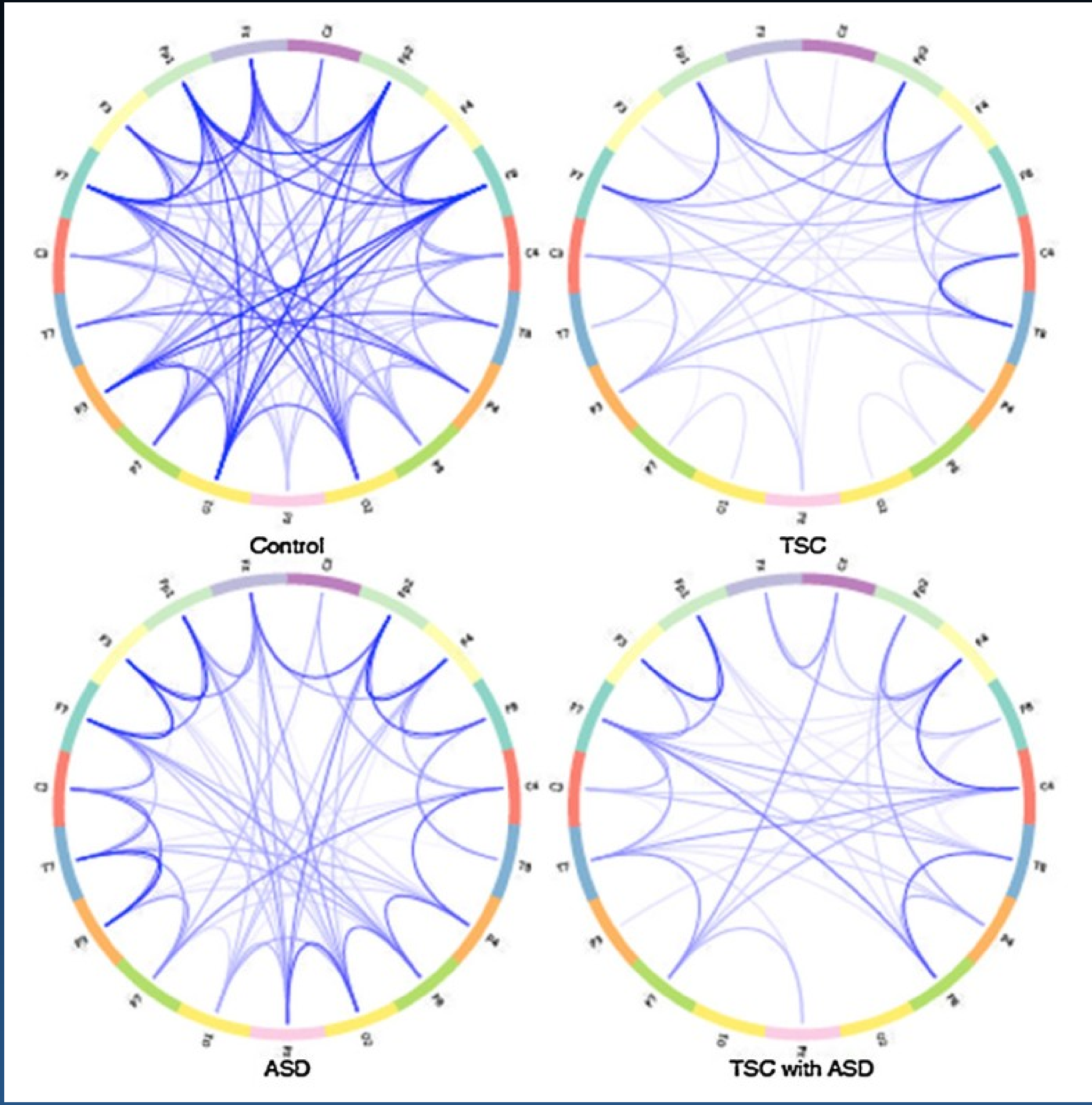
Bullmore & Sporns (2009)

ASD: pathological connections

Comparison of connections for patients with ASD (autism spectrum), TSC (Tuberous Sclerosis), and ASD+TSC.

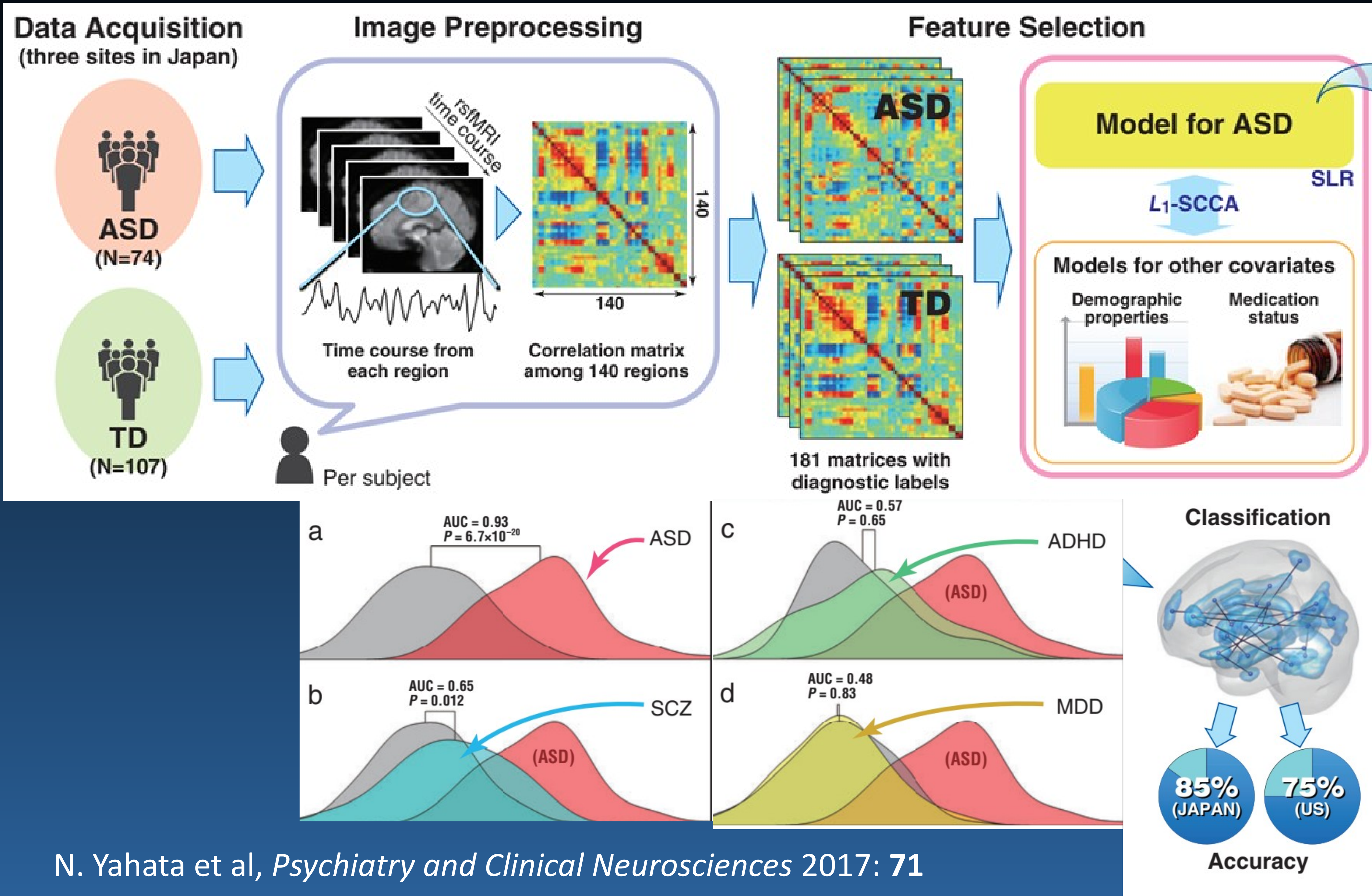
Coherence between electrodes. Weak or missing connections between distant regions prevent ASD/TSC patients from solving more demanding cognitive tasks.

Network analysis becomes very useful for diagnosis of changes due to the disease and learning; **correct your networks**!



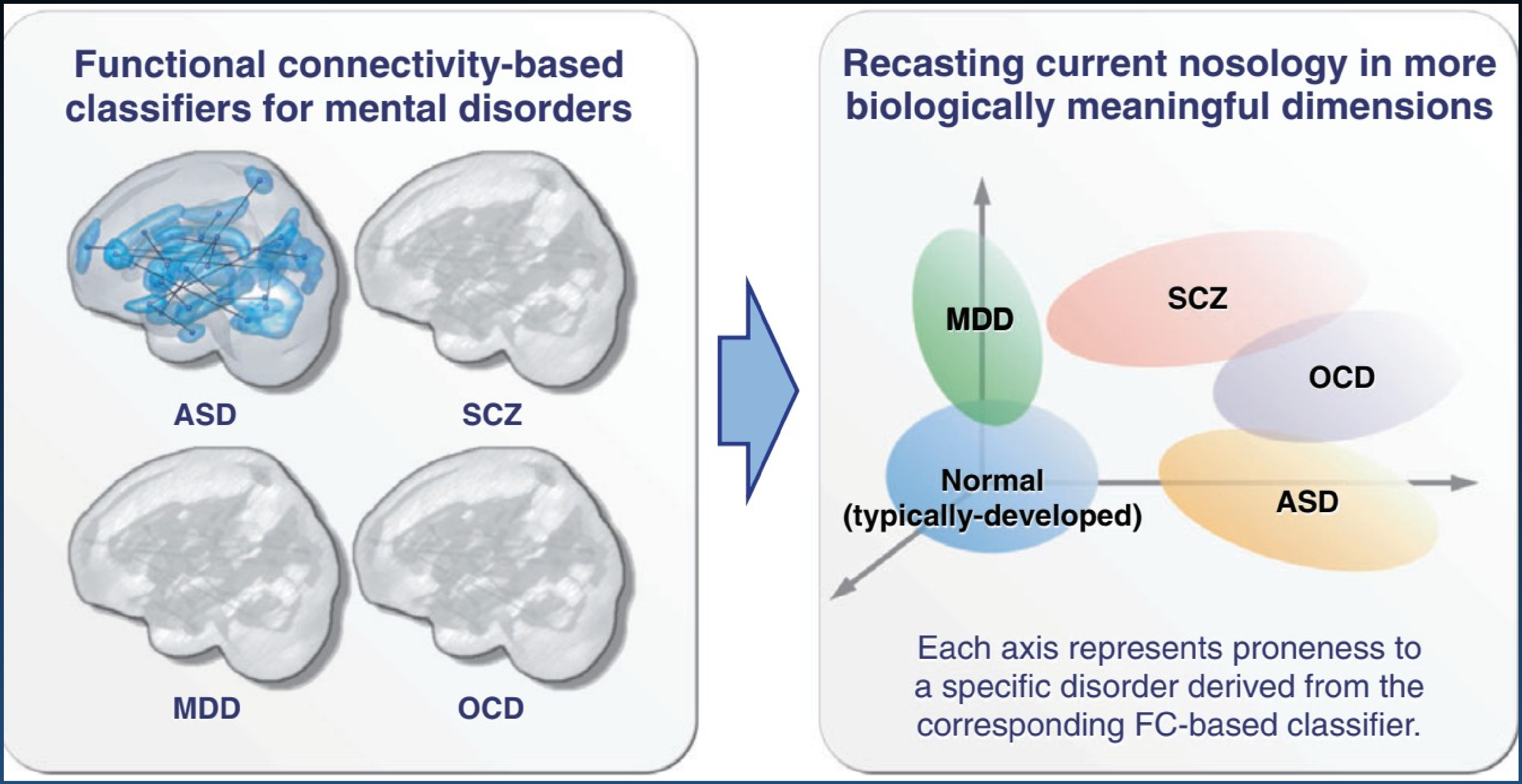
J.F. Glazebrook, R. Wallace, Pathologies in functional connectivity, feedback control and robustness. Cogn Process (2015) 16:1–16

Biomarkers from neuroimaging



N. Yahata et al, *Psychiatry and Clinical Neurosciences* 2017: **71**

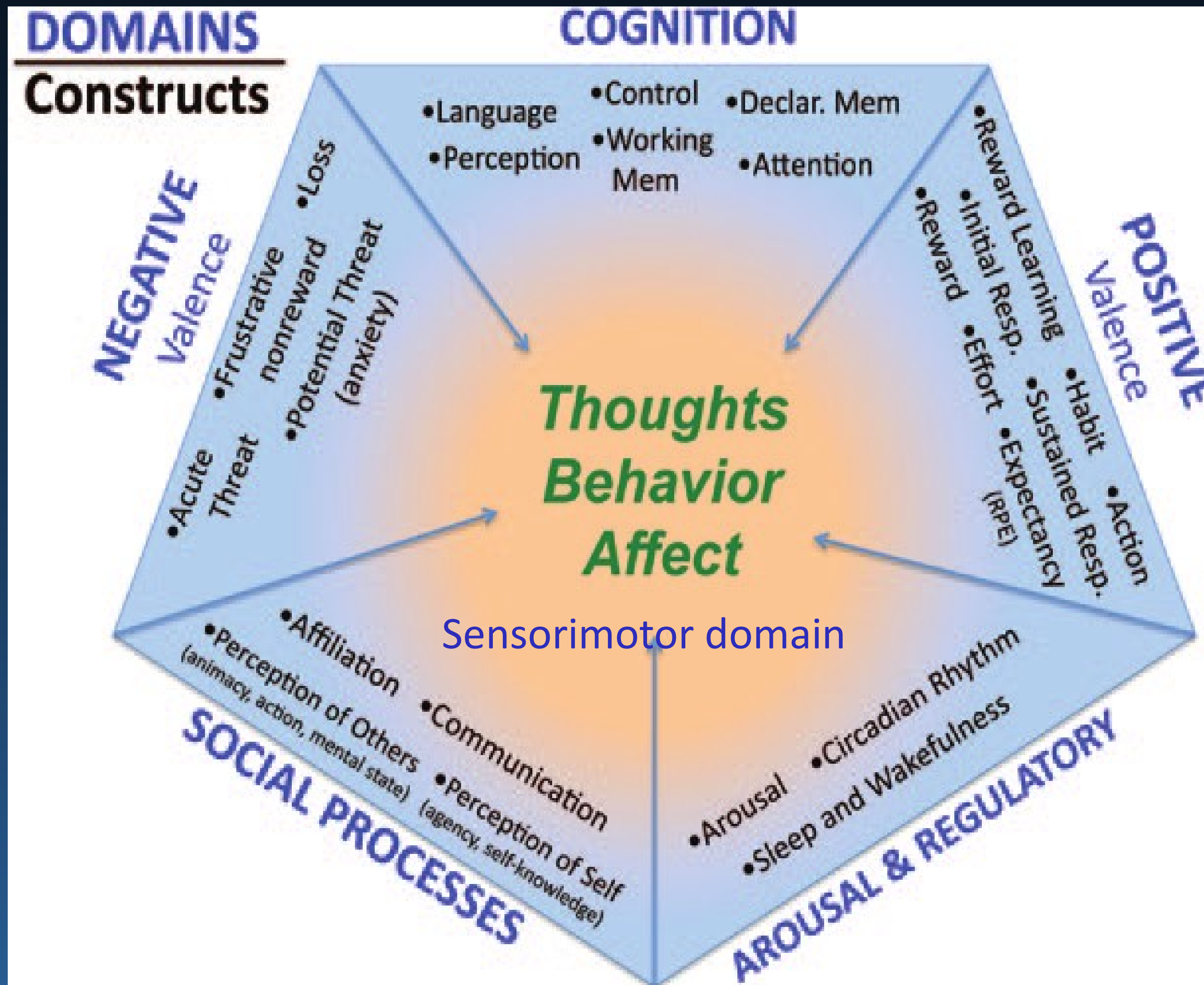
Biomarkers of mental disorders



MDD, deep depression, SCZ, schizophrenia, OCD, obsessive-compulsive disorder, ASD autism spectrum disorder. fMRI biomarkers should allow for objective diagnosis.
N. Yahata et al, *Psychiatry & Clinical Neurosciences* 2017; **71**: 215–237

RDoC
Research Domain Criteria Initiative

NIMH RDoC Matrix for deregulation of 6 large brain systems.



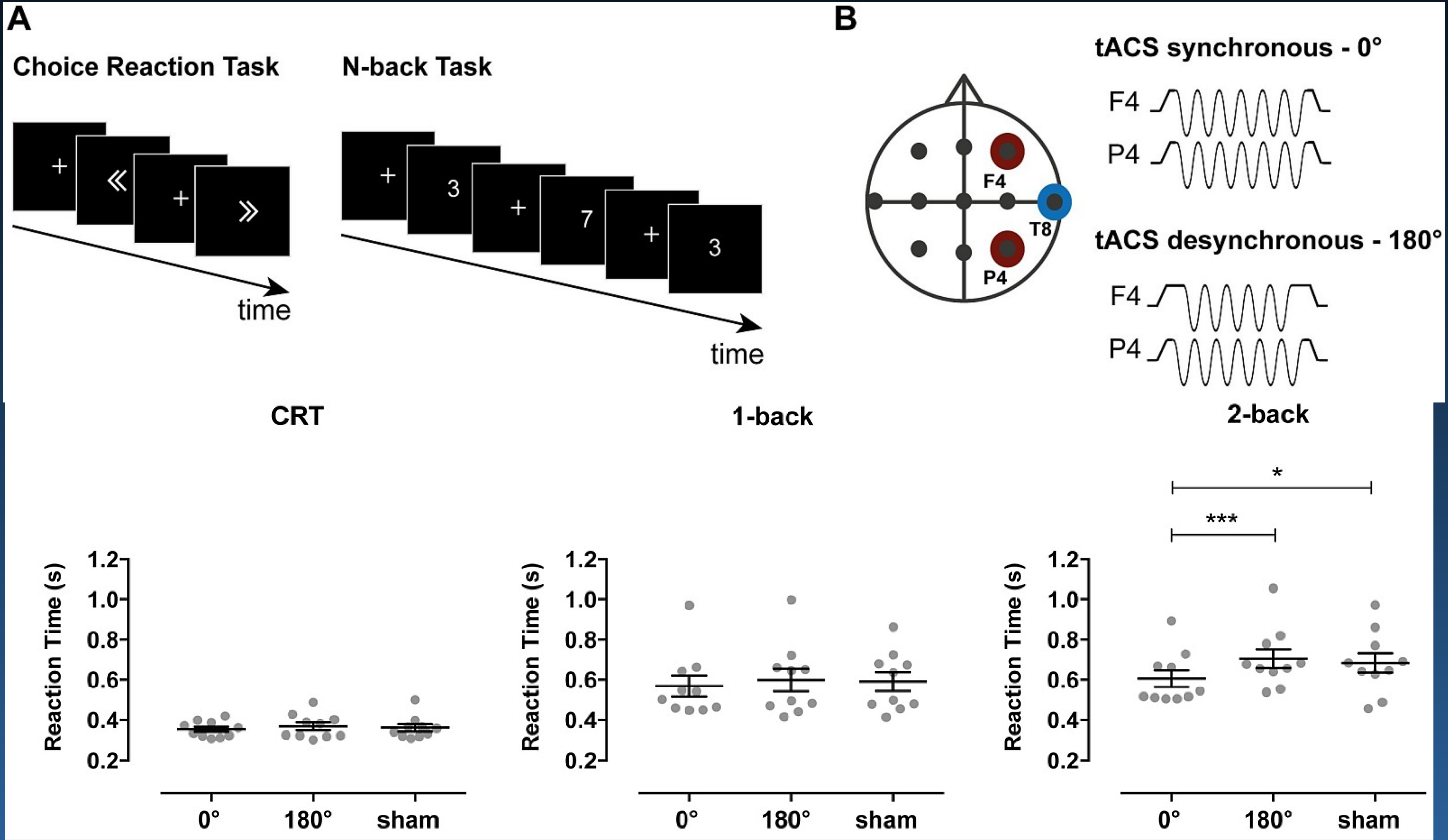
BCBI for learning

Your brain knows better what is interesting than you do!
How to make this information consciously available?

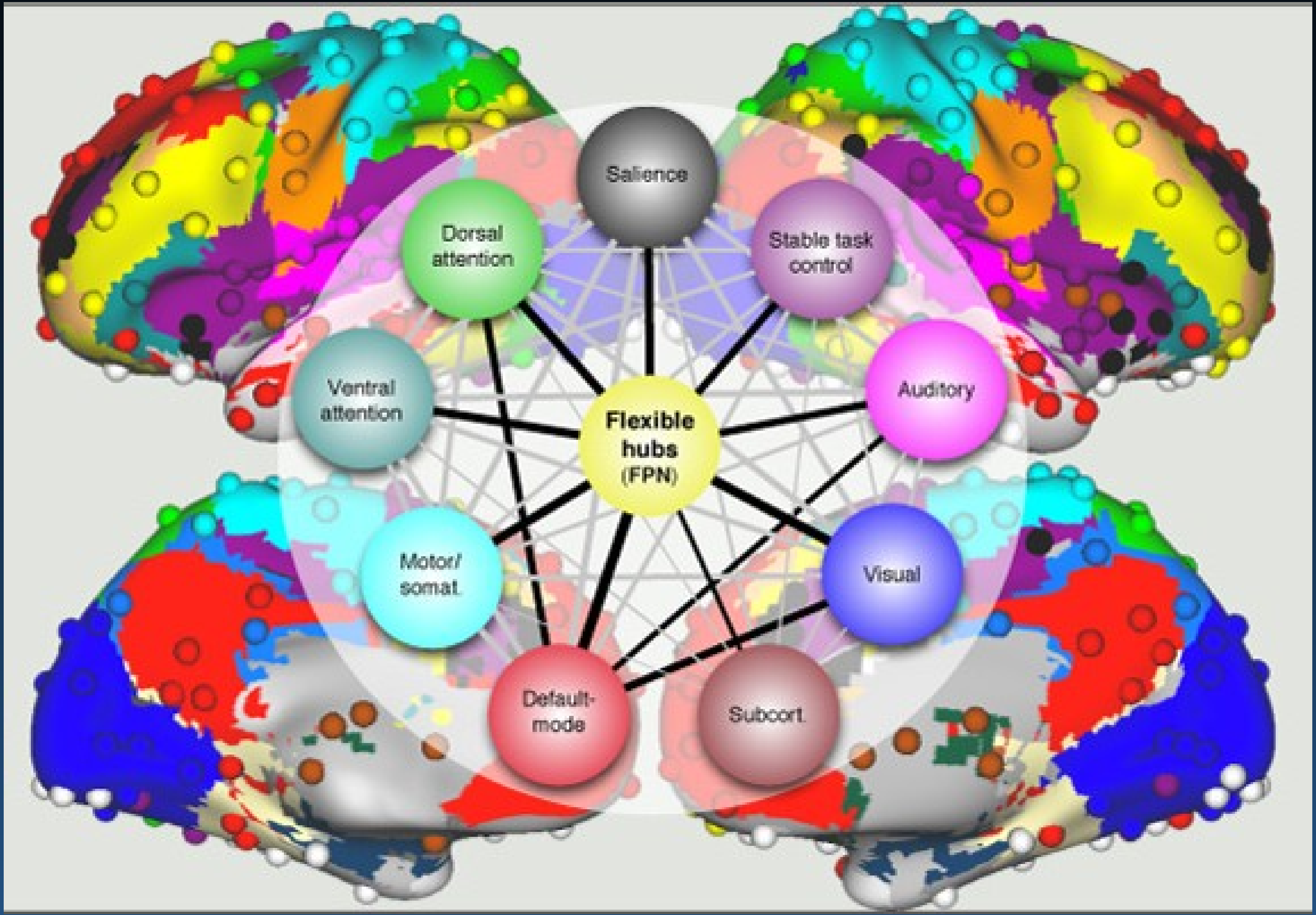
1. Violante I.R. … Sharp D.J. 2017. "Externally Induced Frontoparietal Synchronization Modulates Network Dynamics and Enhances Working Memory Performance." ELife 6:e22001.
2. Eugster, M.J.A. … Kaski S. 2016. "Natural Brain-Information Interfaces: Recommending Information by Relevance Inferred from Human Brain Signals." Scientific Reports 6:38580.
3. Mazurek K.A & Schieber M.H, 2017. "Injecting Instructions into Premotor Cortex". Neuron, 96(6), 1282–1289.e4. Teaching skills by microstimulation of premotor cortex, too low to evoke muscle activation, facilitates specific actions.
4. Yuan Han … West S.G. 2017. "Universal Design for Learning in the Framework of Neuroscience-Based Education and Neuroimaging-Based Assessment." 2nd Int. Conf. on Bio-engineering for Smart Technologies (BioSMART 2017) Neuroimaging based assessment strategy may provide an objective means of evaluating learning outcomes in the application of Universal Design for Learning (UDL), an educational framework created to guide the development of flexible learning environments that adapt to individual learning differences.

Synchronize PFC/PC

Violante, I.R. et al. Externally induced frontoparietal synchronization modulates network dynamics and enhances working memory performance. ELife, 6 (2017).

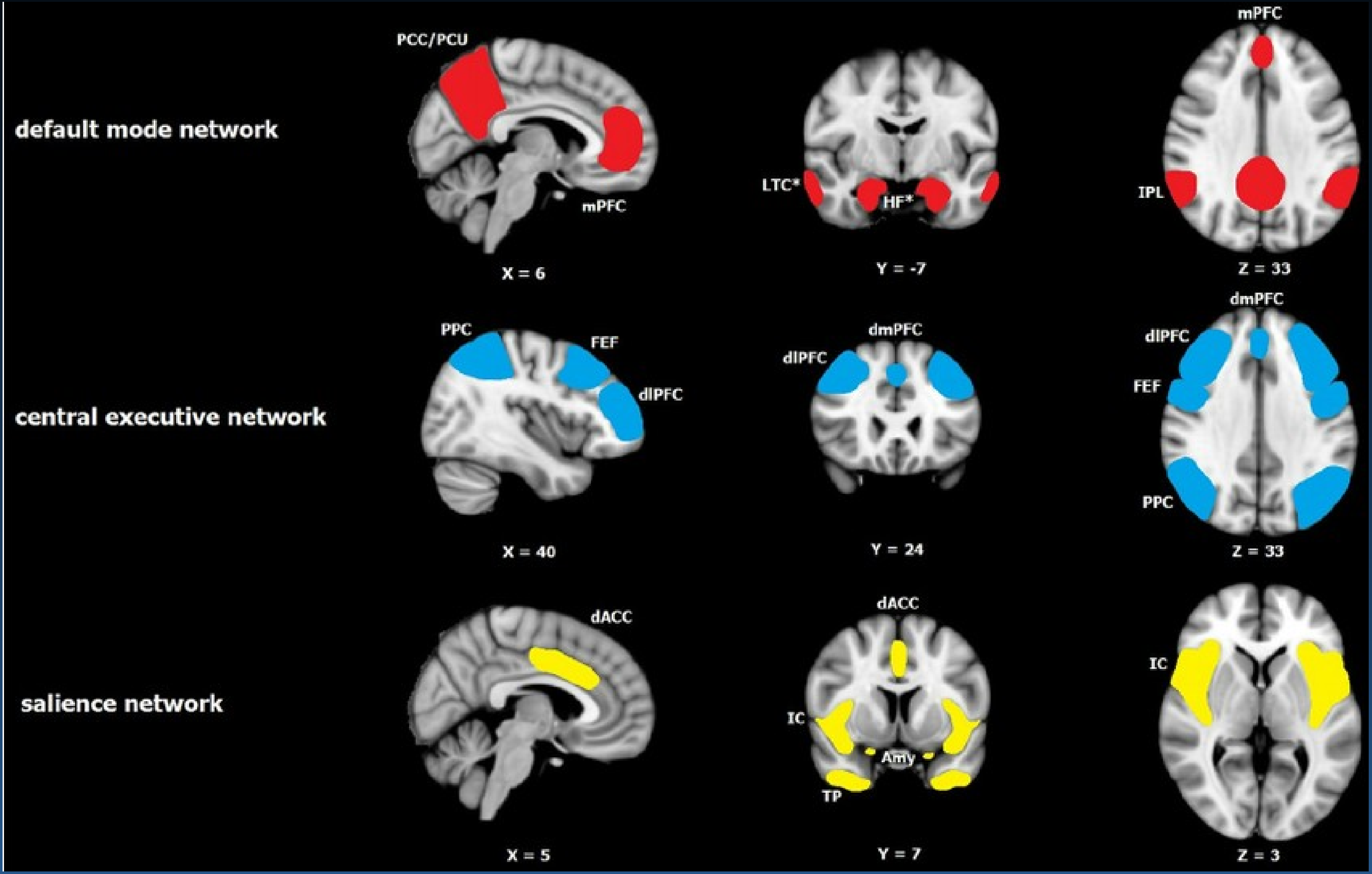


Neurocognitive Basis of Cognitive Control



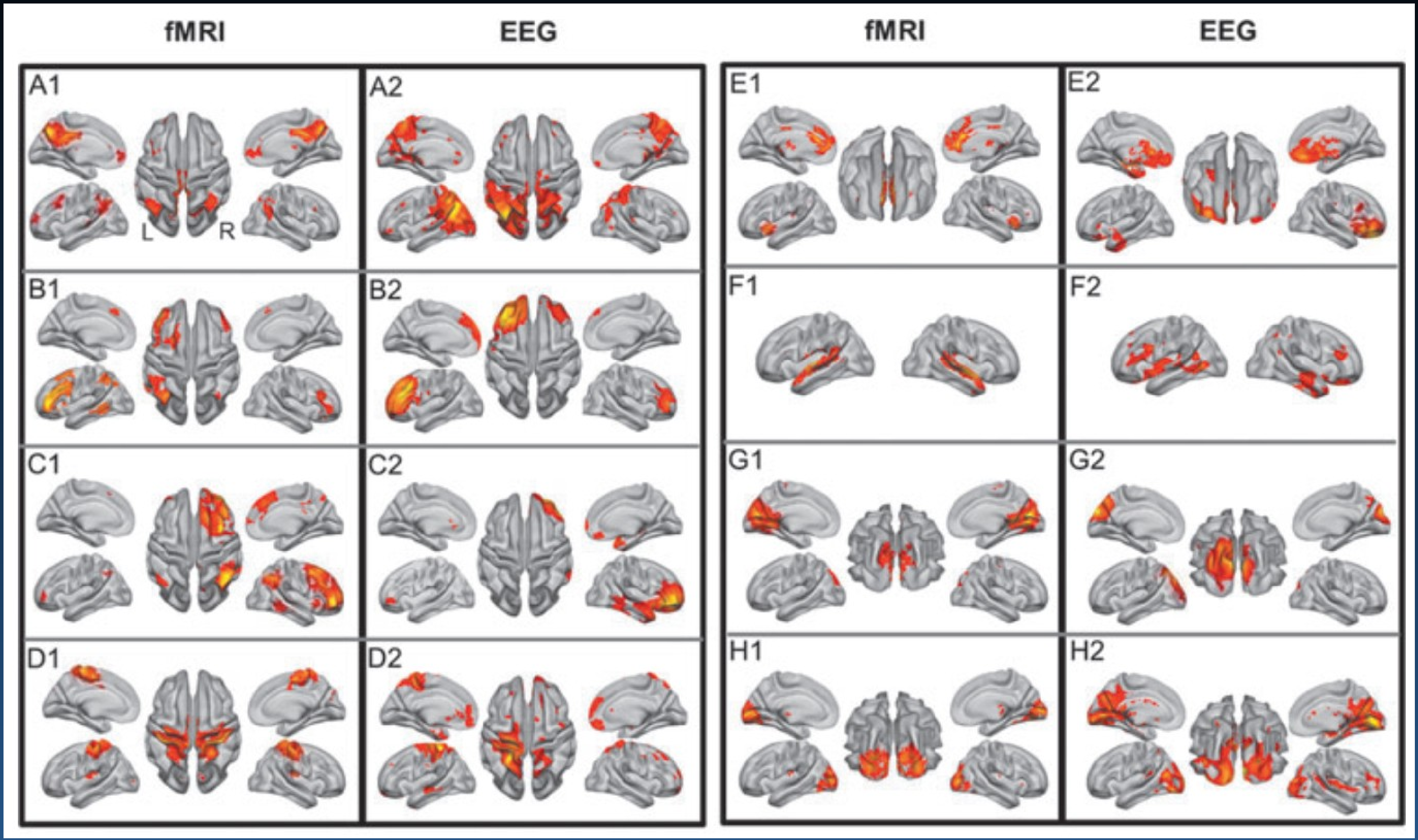
Fronto-Parietal theory of intelligence, control information flow of specialized subnetworks. Ex. Cole M.W. et al. Nature Neuroscience (2013).
Multi-task connectivity reveals flexible hubs for adaptive task control.

DMN, CEN and SN networks



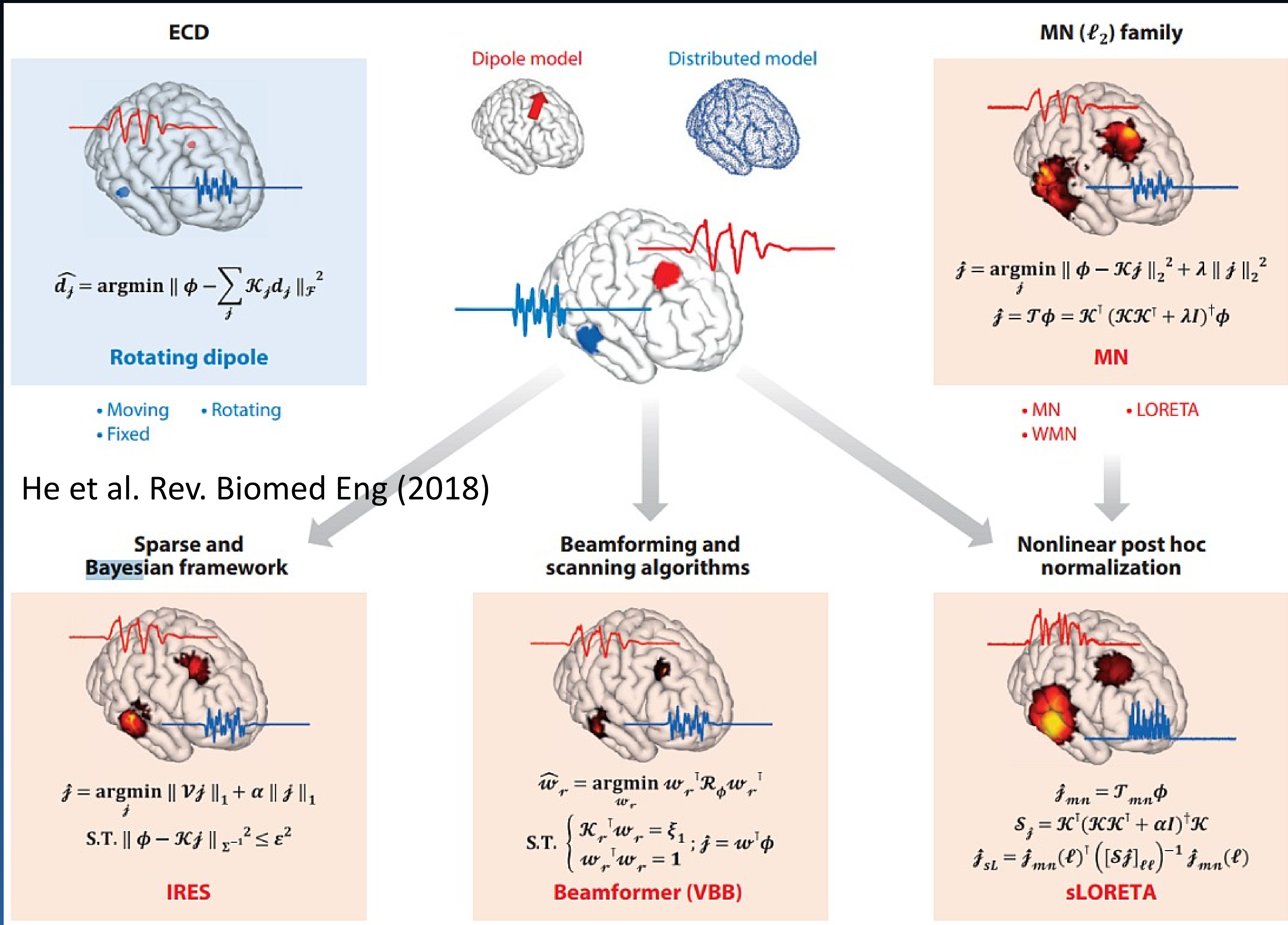
Mulders et al. (2015)

8 large networks from BOLD-EEG



DMN, FP (frontoparietal)-left, right, sensorimotor, ex, control, auditory, visual (medial), (H) visual (lateral). Yuan … Bodurka (2015)

EEG localization and reconstruction



He et al. Rev. Biomed Eng (2018)

SupFunSim

SupFunSim: our library/Matlab /tollbox, direct models for EEG/MEG, on GitHub.

Provides many spatial filters for reconstruction of EEG sources: linearly constrained minimum-variance (LCMV), eigenspace LCMV, nulling (NL), minimum-variance pseudo-unbiased reduced-rank (MV-PURE) …

Source-level directed connectivity analysis: partial directed coherence (PDC), directed transfer function (DTF) measures.

Works with FieldTrip EEG/ MEG software. Modular, object-oriented, using Jupyter notes, allowing for comments and equations in LaTex.

$$A := H_{Src,R} := R^{-1/2} H \qquad (34)$$

$$B := H_{Src,N} := N^{-1/2} H \qquad (35)$$

```
%%file calculate_H_Src.m
function model = calculate_H_Src(MODEL)
    model = MODEL;

    model.H_Src_R = pinv(sqrtm(model.R)) * model.H_Src;
    model.H_Src_N = pinv(sqrtm(model.N)) * model.H_Src;
end
```

Rykaczewski K, Nikadon J, Duch W, Piotrowski T. (2021). *Neuroinformatics 19, 107–125.*

Fingerprints of mental activity

Brain Fingerprinting

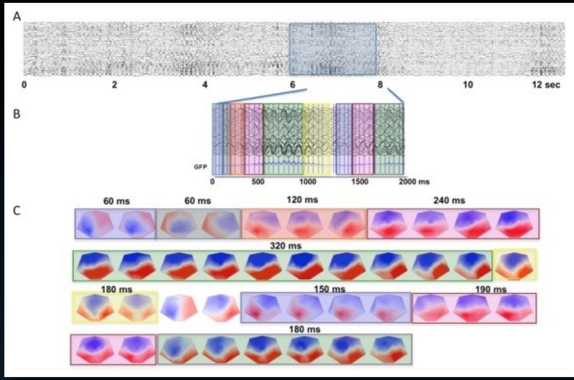
Find unique patterns of brain activity that should help to identify:

- brain regions of interest (ROI)
- active neural networks
- mental states, tasks.

Several approaches:

1. Microstates and their transitions (Michel & Koenig 2018)
2. Reconfigurable task-dependent modes (Krienen et al. 2014)
3. Contextual Connectivity (Ciric et al. 2018)
4. Spectral Fingerprints (Keitel & Gross 2016)
5. A few more …

1



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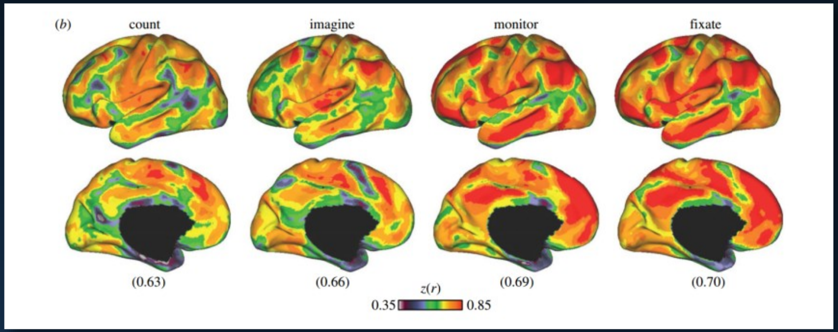

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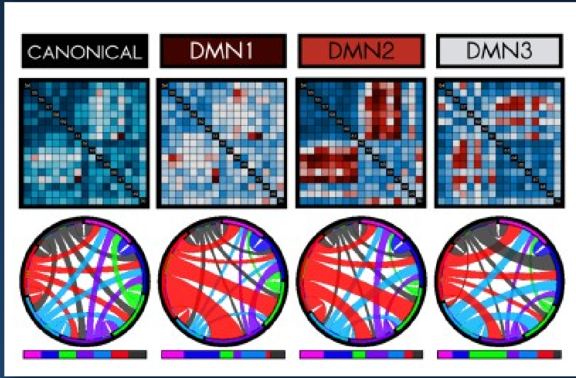

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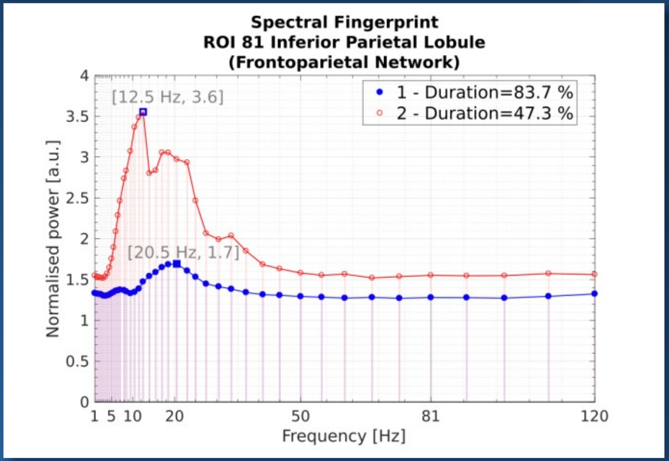


Brain modules and cognitive processes

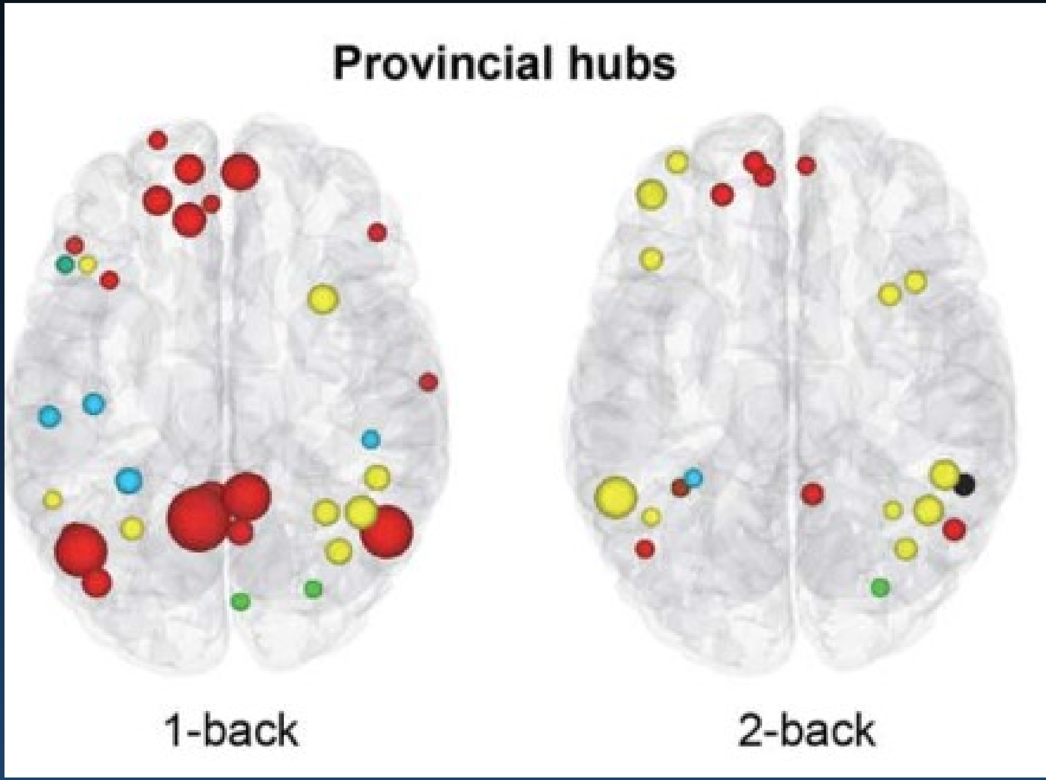
Simple and more difficult tasks, requiring the whole-brain network reorganization.

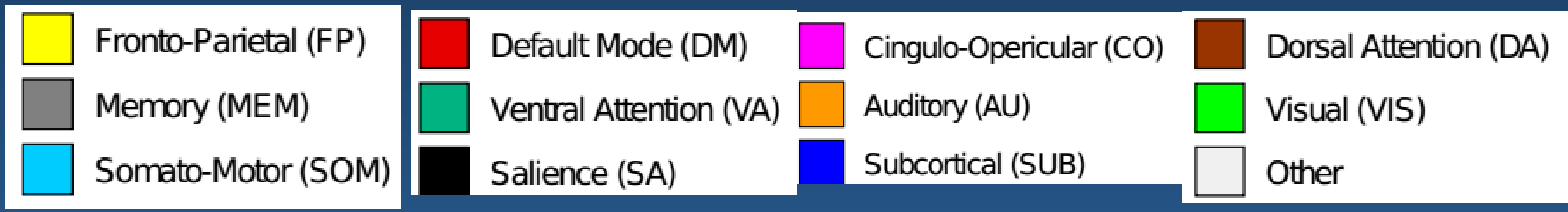
Left: 1-back local hubs

Right: 2-back local hubs

Average over 35 *participants.*

Dynamical change of the landscape of attractors, depending on the cognitive load. Less local (especially in DMN), more global binding (especially in PFC).





K. Finc et al, HBM (2017).

Brain modules and cognitive processes

Simple and more difficult tasks, requiring the whole-brain network reorganization.

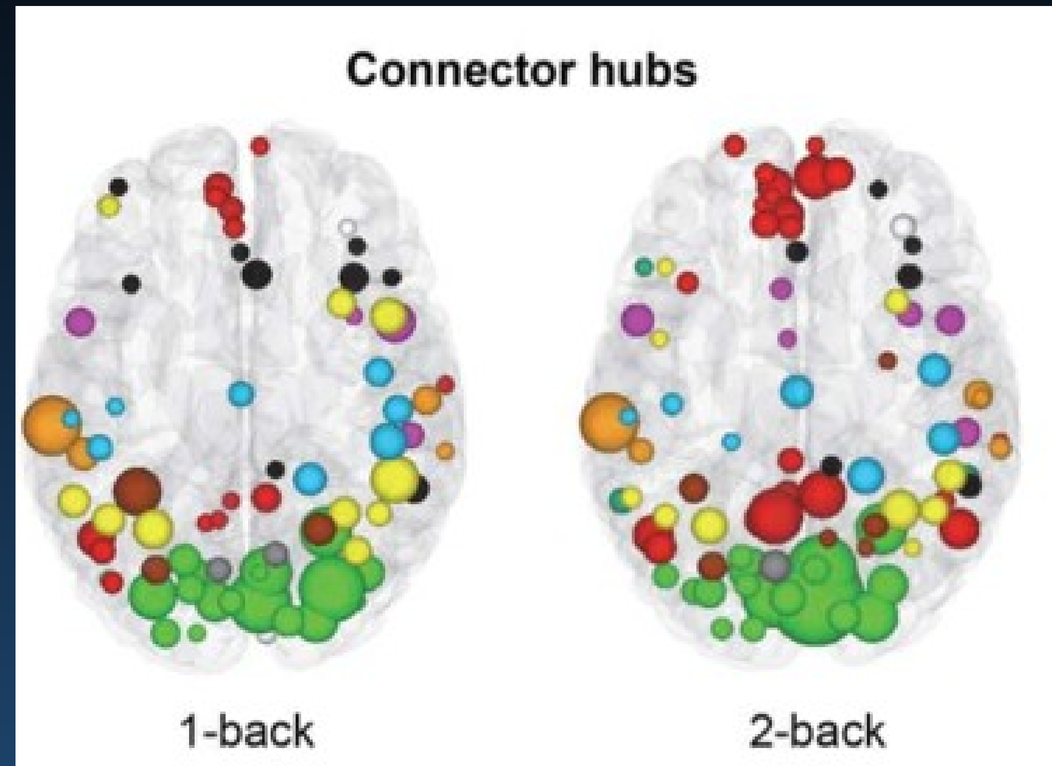
Left: 1-back connector hubs

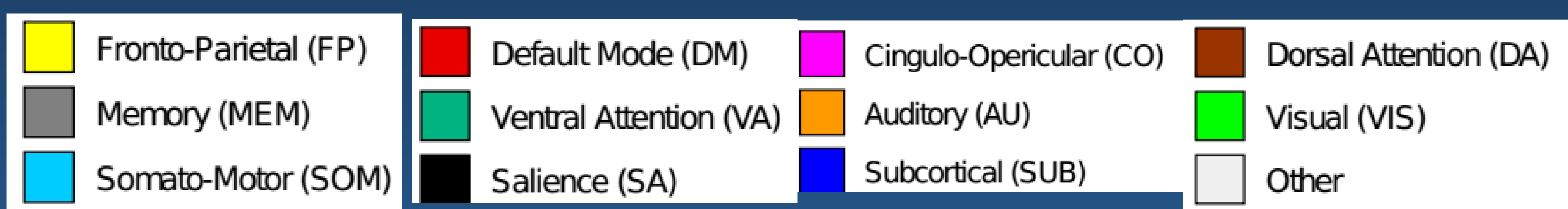
Right: 2-back connector hubs

Average over 35 *participants.*

Dynamical change of the landscape of attractors, depending on the cognitive load – System 2 (Khaneman).

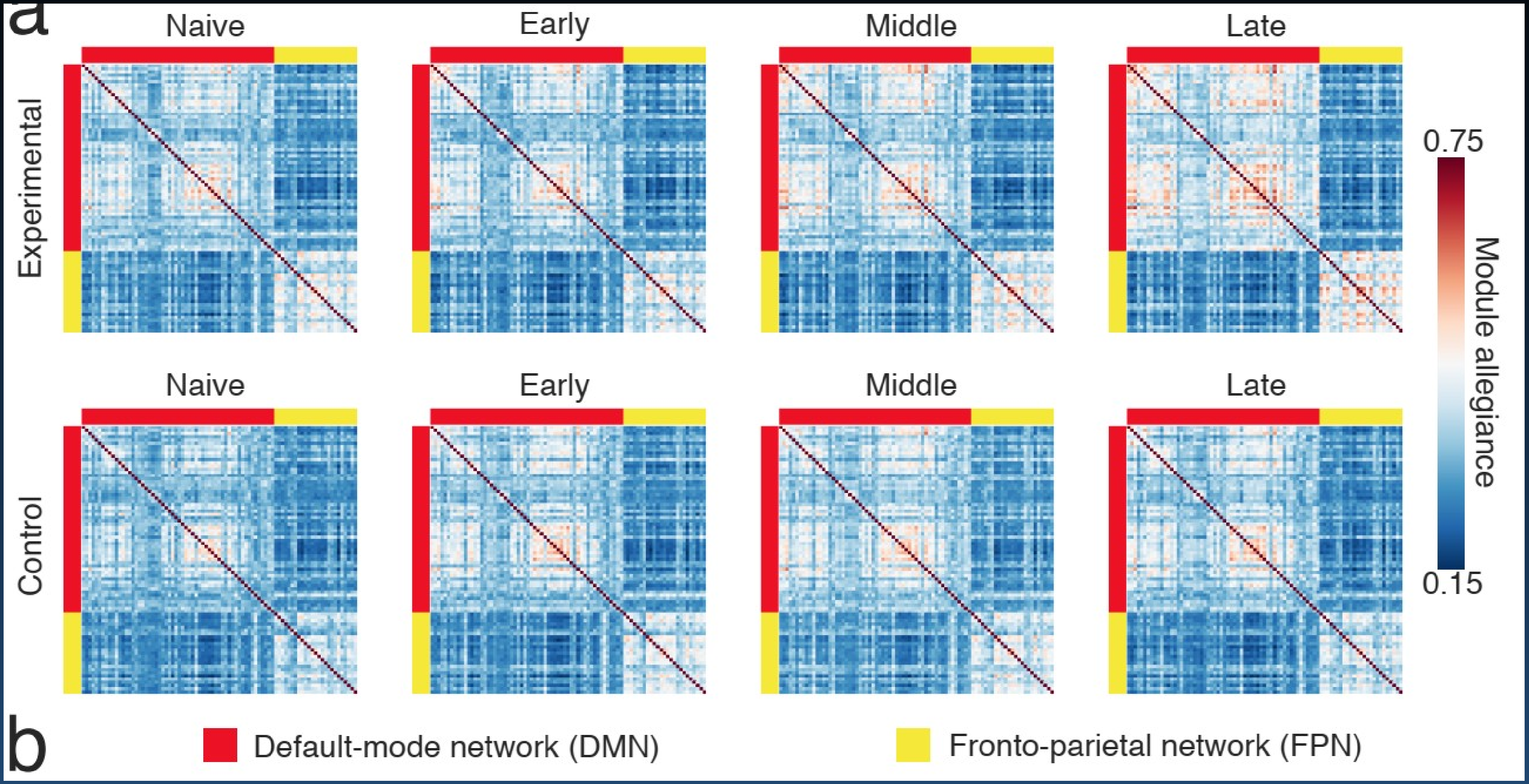
DMN areas engaged in global binding!





Karolina Finc et al, HBM (2017).

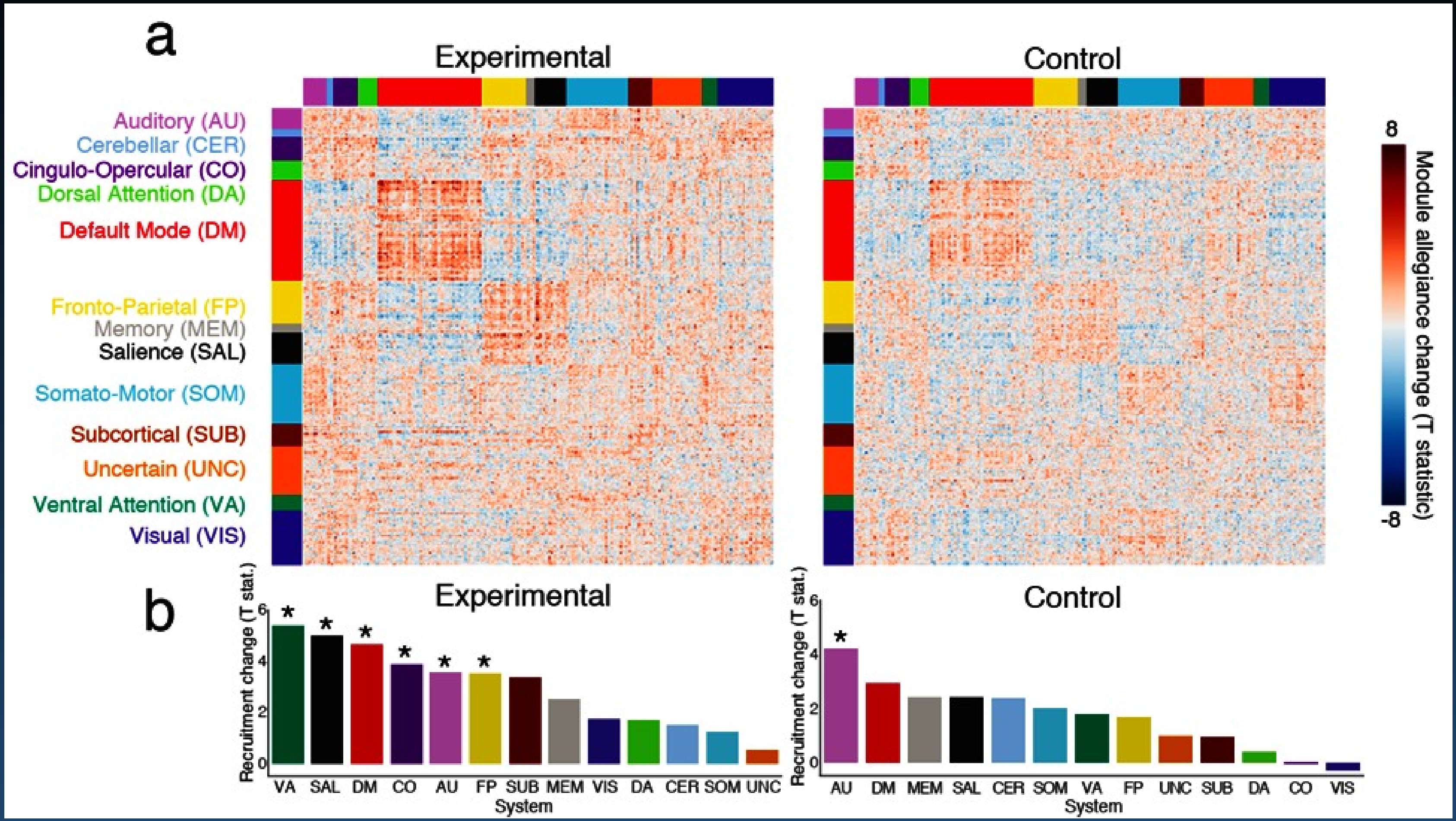
Working memory training



6-week training, dual n-back task, c**hanges in module allegiance of fronto-parietal and default-mode networks.** Each matrix element represents the probability that the pair of nodes is assigned to the same community.

Segregation of task-relevant DMN and FPN regions is a result of training and complex task automation, i.e. from conscious to automated processing.

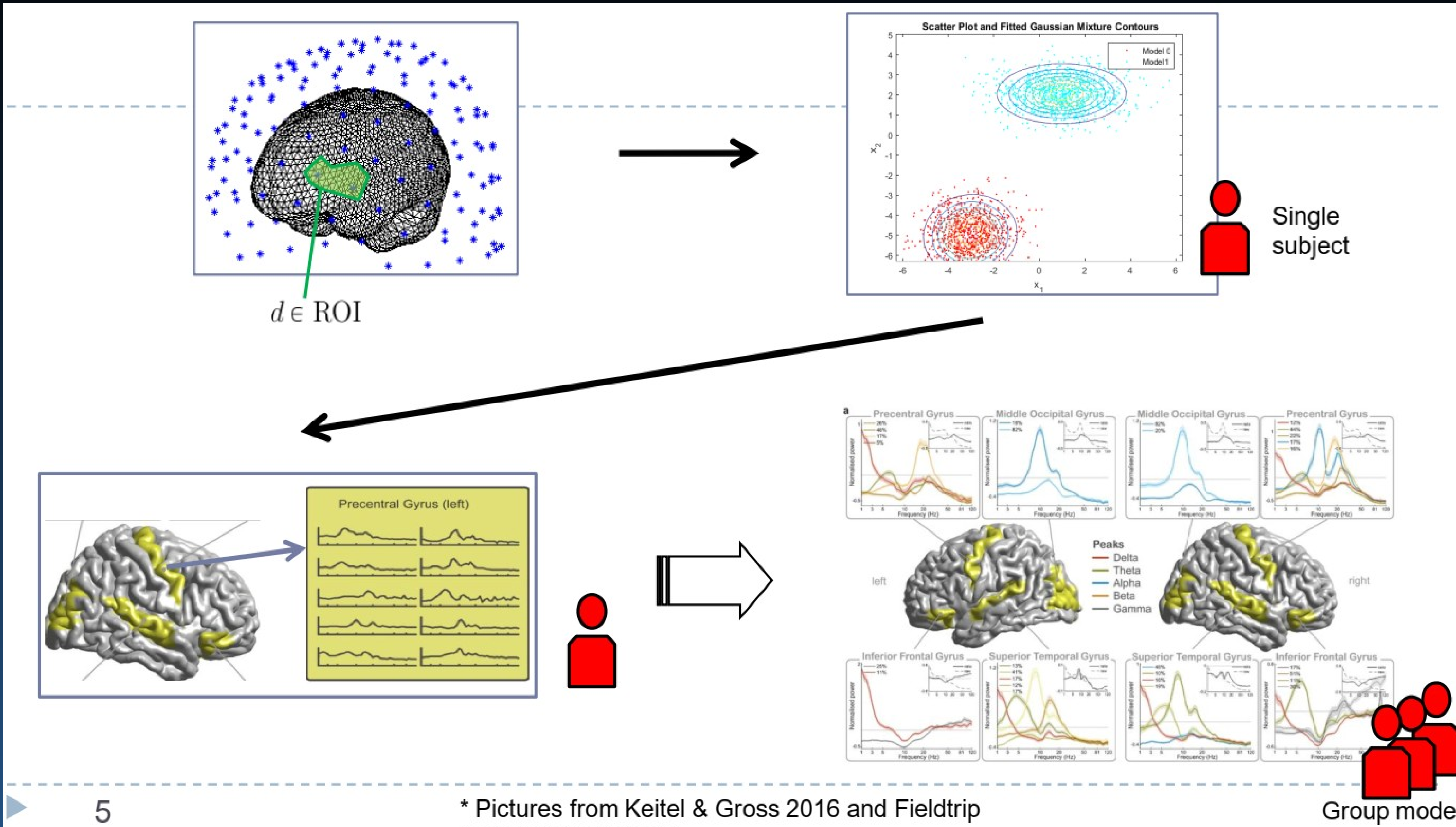
Working memory training



Whole-brain changes in module allegiance after 6-week of WM training.
(a) Changes in node allegiance as reflected in the two-tailed *t*-test.
(b) Significant increase * in the default mode DM, fronto-parietal ventral attention VA, salience SAL, cingulo-opercular CO, and auditory systems AU recruitment.

K. Finc, K. Bonna, … W. Duch, D. Bassett, Nature Communications 11 (2020)

Spectral fingerprints



A. Keitel i J. Gross, „Individual human brain areas can be identified from their characteristic spectral activation fingerprints”, *PLoS Biol* 14(6), e1002498, 2016

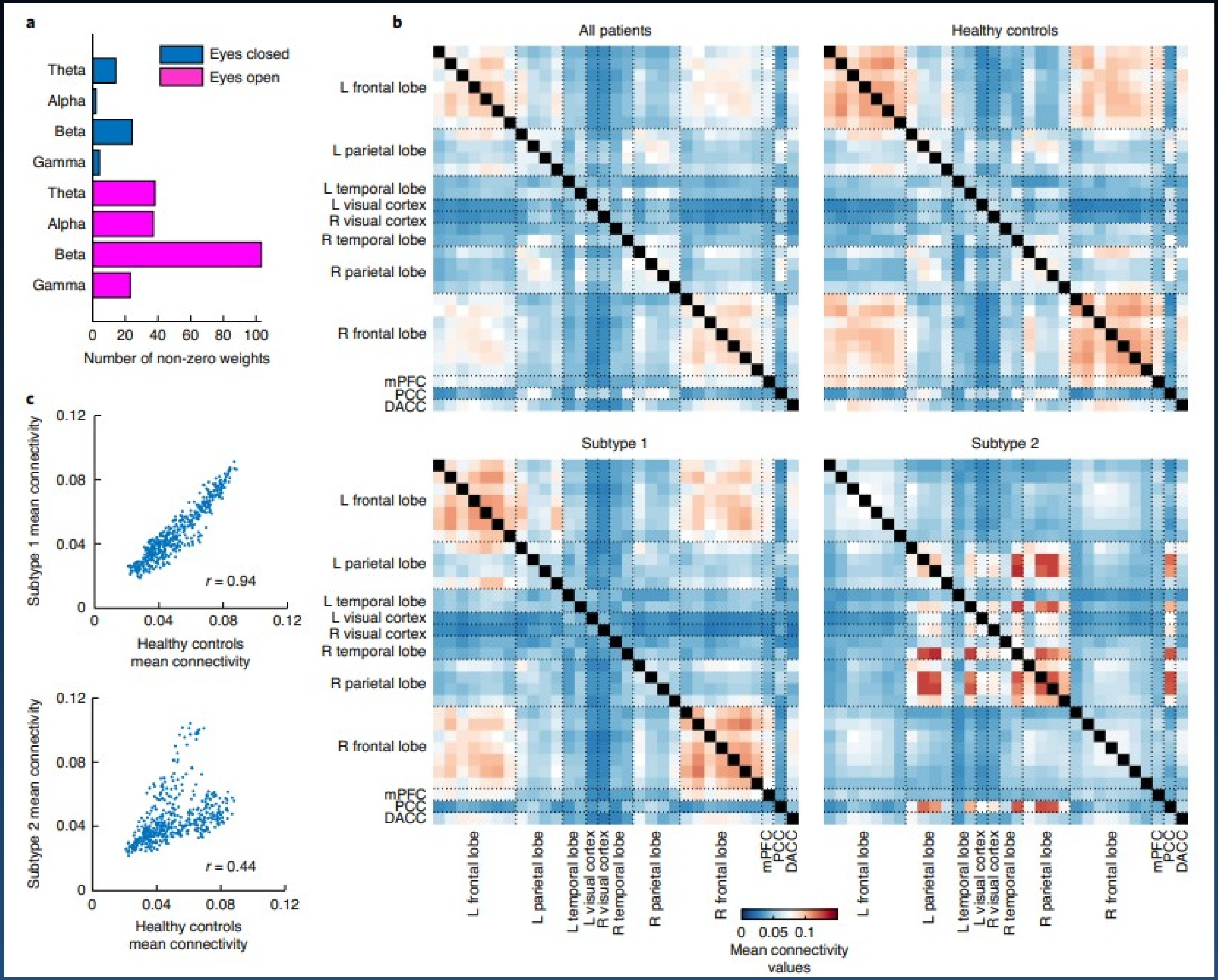
Subtypes ofMD/PTSD from EEG!

PEC (power envelope connectivity) across 31 ROIs, 4 bands (theta, alpha, beta, gamma), eyes open and eyes closed).

a, Number of non-zero feature weights for different conditions as a result of sparse clustering.

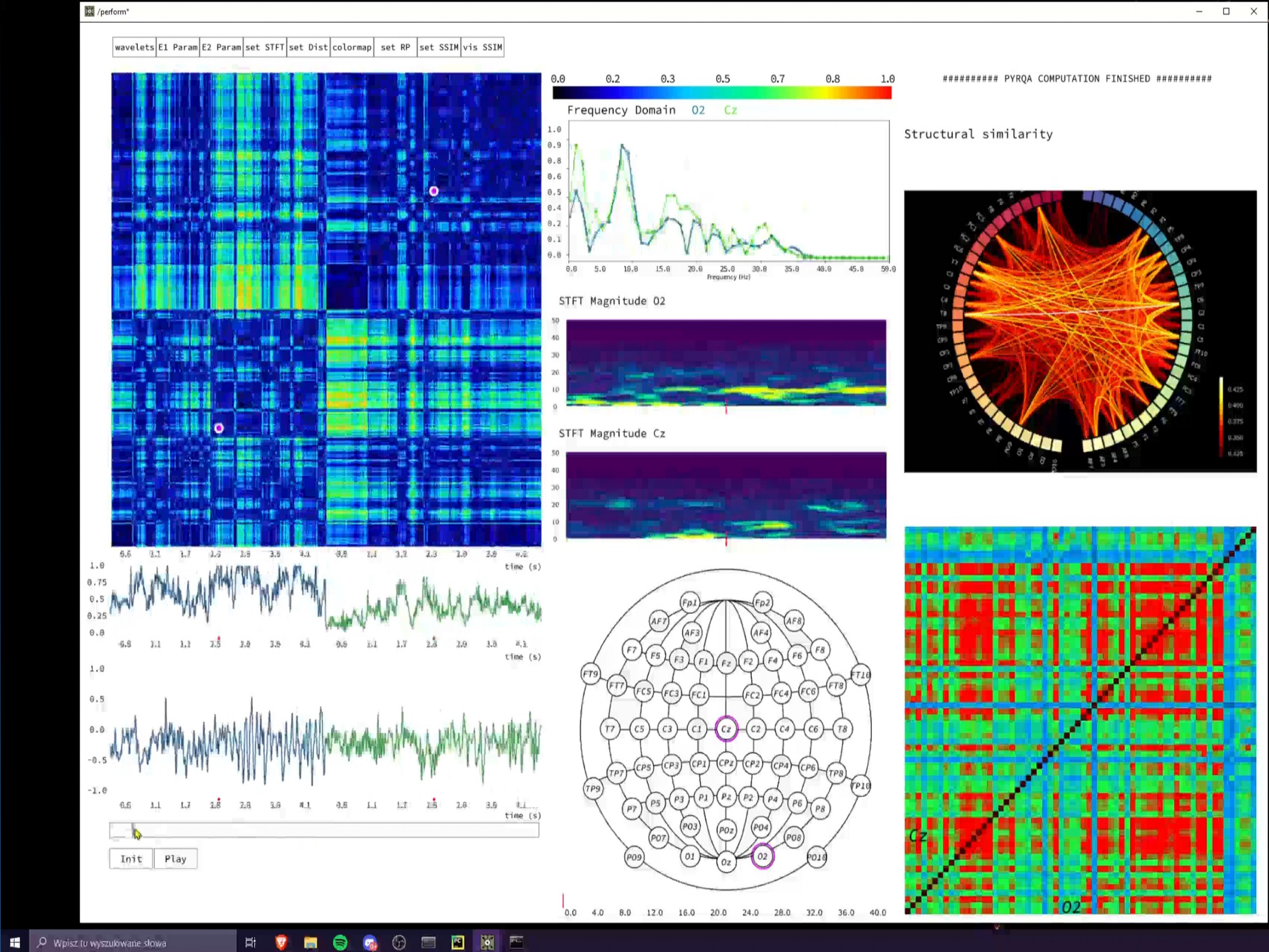
b, Mean connectivity of all patients, healthy controls and PTSD subtypes, beta band/eyes-open.

All/healthy similar. Subtype 2 is quite different, frontal connectivity is very low.



Two subtypes of major depression, and two subtypes of PTSD, responding in a different way to TMS, identified from dynamical functional connections analysis.

Zhang et al. (2021). Identification of psychiatric disorder subtypes from functional connectivity patterns in rsEEG. Nature Biomedical Engineering, 5(4), 309–323.


/perform*
wavelets
E1 Param
E2 Param
set STFT
set Dist
colormap
set RP
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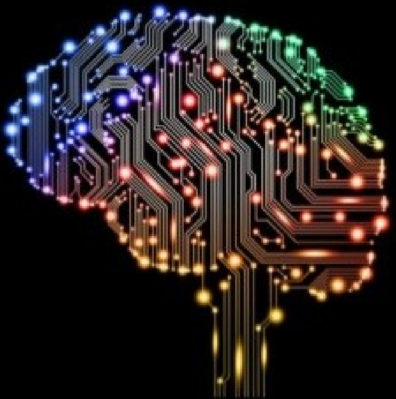
0.0 0.2 0.3 0.5 0.7 0.8 1.0
########## PYRQA COMPUTATION FINISHED ##########
Frequency Domain O2 Cz
Frequency (Hz)
Structural similarity
STFT Magnitude O2
STFT Magnitude Cz
time (s)
Init
Play
Fp1 Fp2 AF7 AF3 AF4 AF8 F7 F5 F3 F1 Fz F2 F4 F6 F8 FT9 FT7 FC5 FC3 FC1 FC2 FC4 FC6 FT8 FT10 T7 C5 C3 C1 Cz C2 C4 C6 T8 TP7 CP5 CP3 CP1 CPz CP2 CP4 CP6 TP8 TP9 TP10 P7 P5 P3 P1 Pz P2 P4 P6 P8 PO7 PO3 POz PO4 PO8 PO9 O1 Oz O2 PO10
Cz
O2
Wpisz tu wyszukiwane słowa

AI for Neuroscience
&
Neuroscience for AI



Irina Rish
AI Foundations
IBM T.J. Watson Research Center

Neuroscience⇔ AI ⇔Neuroscience

Machine learning techniques analyse neuroimaging data.

Hassabis, D., Kumaran, D., Summerfield, C., Botvinick, M. (2017). Neuroscience-Inspired Artificial Intelligence. *Neuron*, *95*(2), 245–258.
Bengio, Y. (2017). The Consciousness Prior. ArXiv:1709.08568.

Ideas from animal psychology helped to give birth to reinforcement learning (RL) research. Now **key concepts from RL inform neuroscience**. Brain implements a form of temporal difference learning!

LSTM architecture provides key insights for development of working memory, gating-based maintenance of task-relevant information in the prefrontal cortex.

AI Systems inspired by Neural Models of Behavior:

- Visual attention, foveal locations for multiresolution ‘‘retinal’’ representation.
- Complementary learning systems and episodic control: fast learning hippocampal system and parametric slow-learning neocortical system.
- Models of working memory and the Neural Turing Machine.
- Neurobiological models of synaptic consolidation algorithm.

Neuroscience => AI

Examples of recent AI systems inspired by neuroscience:

- **Intuitive physics knowledge**, reason and make predictions about the physical interaction between objects, predict trajectories, collisions, gravitational forces.
- **Scene understanding** through structured generative models. Recurrent network attends to one object at a time, infers its attributes, and performs the appropriate number of inference steps for each input image in realistic scene.
- **Unsupervised learning of core object properties** by deep generative model based on variational auto-encoder, that can learn intuitive concepts such as ‘‘objectness,’’ being able to support zero-shot transfer (i.e., reasoning about position or scale of an unseen object with a novel shape).
- **One-shot generalization** in deep sequential generative models that specify a causal process for generating the observed data using a hierarchy of latent variables, with attentional mechanisms supporting sequential inference, mirroring human abilities to generalize from a single concept.
- **Imagination of realistic 3D environments** in deep neural networks by an action-conditional recurrent network model, reinforcement learning in simulation-based planning.

Exciting applications

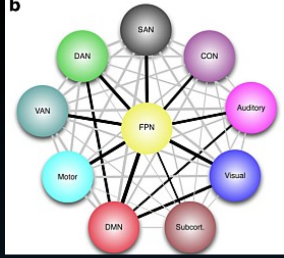
- **Monitoring development** of children and infants, perception, working memory, curiosity, unfolding full potential of children!
- Precise **diagnosis** of various subtypes of mental disorders: organic problems, schizophrenia, epilepsy, learning disabilities, depression, anhedonia, mild cognitive impairment, Alzheimer etc, based on brain connectivity and functional large scale networks.
- Enabling early ASD diagnosis and other **developmental problems**.
- Novel more effective forms of **neurofeedback**; for attention deficits, drug addiction, ASD, MCI and other problems.
- Nonpharmacological approaches to various forms of **pain management through closed-loop neuromodulation**; distinguishing between organic, chronic, psychogenic and faking pain, and provide treatment based on neuromodulation.

Estimation: 27 B$ market for neural devices in 2025.

More benefits

- **Closed loop neurofeedback for neurorehabilitation**: discovering deficits in information flow in the brain, targeting neuroplasticity in specific brain areas to form new functional connections.
- Improvement in EEG-based **brain-computer interfaces**, new neurofedback/BCI in information retrieval and situation awareness.
- **Disorders of consciousness** – better diagnosis and communication with patients in coma.
- **Applications in education**: testing for problems such as dyslexia or dyscalculia, lack of musical imagery, objective assessment of learning outcomes and individual learning differences.
- **Memory improvement** through neuromodulation and in future deep brain stimulation.
- Neurocognitive technologies for general optimization of brain processes, well-being, wisdom, entertainment.

Recent papers from our lab



- Finc K, … Bassett, D.S. (2020). Dynamic reconfiguration of functional brain networks during working memory training. **Nature Communications** 11, 2435.
- Esteban, O. … Gorgolewski, K. J. (2020). Analysis of task-based functional MRI data preprocessed with fMRIPrep. **Nature Protocols** 15, 2186–2202.
- Thompson, W.H. … Poldrack, R. A. (2020). Time-varying nodal measures with temporal community structure: A cautionary note to avoid misinterpretation. **Human Brain Mapping**, 41(9), 2347-2356.
- Bonna, K … Szwed, M. (2020). Early deafness leads to re-shaping of global functional connectivity beyond the auditory cortex. **Brain Imaging and Behaviour** 15, 1469–1482.
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- Rykaczewski K, Nikadon J, Duch W, Piotrowski T (2021). SupFunSim: spatial filtering toolbox for EEG. **Neuroinformatics** 19, 107–125
- Duch W (2021). Memetics and Neural Models of Conspiracy Theories. **Patterns**. Cell Press. j.patter.2021.100353
- Ratajczak E, Hajnowski M, Stawicki M, Duch W. (2021). Novel methodological tools for behavioral interventions: the case of HRV-biofeedback. Sensors 21(11), 3670

In search of the sources of brain's cognitive activity

Project „Symfonia 4”, 2016-22

FACULTY OF PHYSICS, ASTRONOMY AND INFORMATICS

CENTRE FOR MODERN INTERDISCIPLINARY TECHNOLOGIES

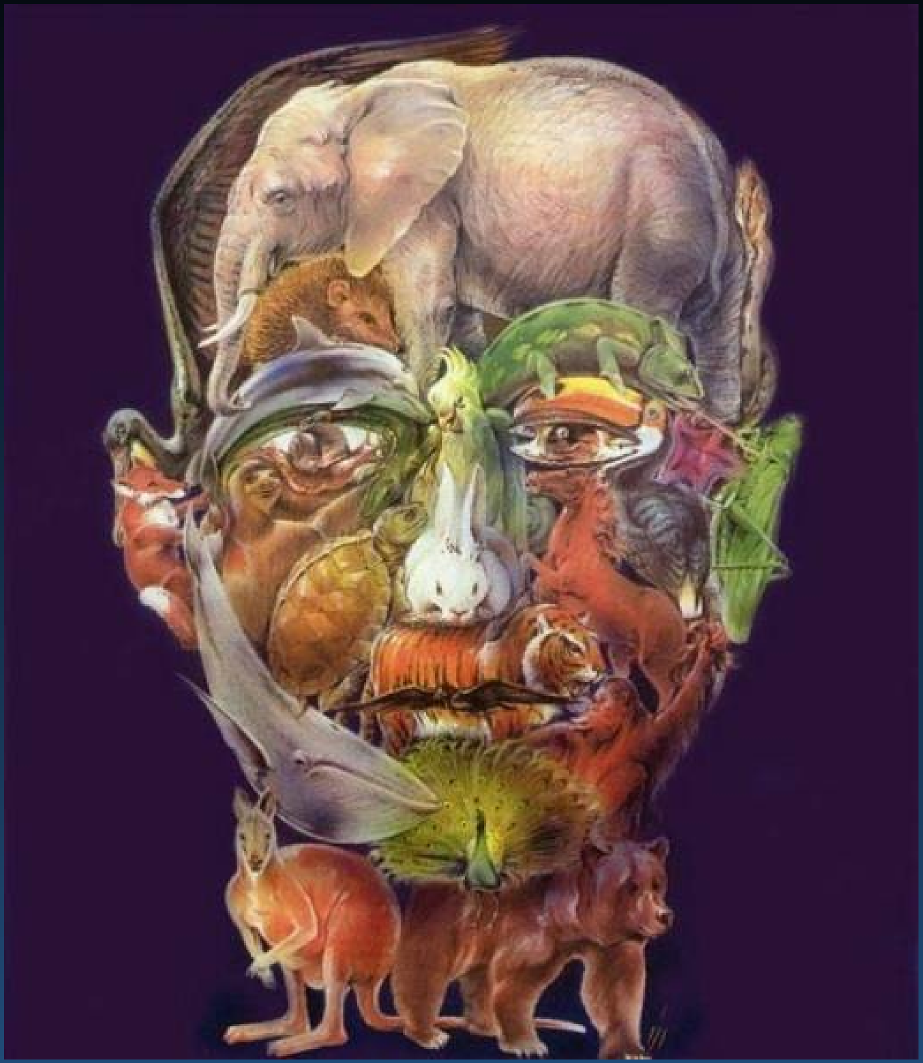
INSTITUTE OF PHYSIOLOGY AND PATHOLOGY OF HEARING

nencki institute of experimental biology

Thank you for synchronizing your neurons!

Our Center of Excellence in Neuroinformatics (DAMSI) has open positions for PhD students, postdocs and visiting profs from abroad!
Please join our efforts!

Info is on our DAMSI webpage



Google: Wlodek Duch
=> talks, papers, lectures, Flipboard …